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Atmospheric Effects and Behaviour of Electromagnetic Signals in the Millimeter Wave Range Wireless Communication

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Abstract*- Today, in 2022 evolution of 5G is at its peak, and few companies have even launched their smartphones based on LTE-A as a primary technology and in non-standalone mode. Millimeter wave communication using electromagnetic signals plays a vital role. This electromagnetic signal, when propagates through the air, may get impacted by various atmospheric constituents like free space loss, rain attenuation loss, gaseous loss, foliage loss, humidity, cloud, fog, and penetration loss. These losses cannot be underestimated during estimation and performance analysis in the high-frequency region of millimeter wave communication. An atmospheric constituent causes a very high degree of attenuation in the millimeter wave range and reduces transmission range when intended for non-line of sight communication. Accurate and precise measurements and analysis of these parameters help suggest new and better models in designing and development of millimeter wave range advanced communication systems. Though no model is a hundred percent correct, it is possible to measure these losses accurately and precisely by effective modeling. The new models are suggested by taking into consideration tropical and temperate regions. We need new models for a specific place in tropical areas to get precision, accuracy, and better performance in the millimeter wave range. This paper remits the effect of atmospheric constituents in the new models developed for a tropical region like Navi Mumbai in India for millimeter wave communication in the range of 30 GHz to 300 GHz.

Index Terms*- Attenuation Region, Atmospheric losses, Electromagnetic signal, Millimeter Wave, Models.

I. INTRODUCTION

When an electromagnetic signal is propagated through the air, it has been impacted by different atmospheric impairments like free space loss, rain attenuation loss, gaseous loss, foliage loss, fog, cloud, and humidity. As the millimeter wave signal passes through the environment, it writhes due to frequency-dependent absorptive and dispersive phenomena distorting amplitude and phase [1]. So, it became necessary to analyze the fact as it affects mobile communication in the millimeter wave range, i.e., 30GHz to 300GHz. Most of the literature is available in temperate regions, and we need to estimate these parameters for tropical regions. New models have to be developed for dense environment places. Free space loss and rain attenuation loss have a more significant effect than other types of losses. In wireless communication, where different interferences impact the path, we cannot ignore the performance degradation because of these environmental constituents. It is not possible to avoid the signal loss due to atmospheric effects. Still, with accurate measurement and predictive models, those can be accurately measured, which will help design millimeter wave communication systems.

Communication route loss simulations refer to envisage air route features such as obtained excitation capability, multipath impacts, and interference [2]. When EM waves are propagated in the space, the energy is transferred in photons. When these photons bump with particle molecules, the phenomena like absorption and emission take place, and part of the energy will get scattered. When the energy of an electron moving in a higher orbit is equal to the energy of a photon, the EM waves will get absorbed. In contrast, when this energy is not equal to the energy of photon phenomena, emission takes place. The whole globe has been divided into temperate regions and tropical regions. International Telecommunication Union (ITU) has published its standard as a reference. India and Africa-like countries come in tropical regions. Site measurements or metrological centers can obtain the data. It is analyzed and used as a reference to calculate losses. Because of some medium effects, some other attenuation losses are also imposed. The free-space loss and medium loss products are referred to as basic transmission loss and given by eqn. 1.

$$Lb = FSL * Lm \tag{1}$$

Where Lb = Basic transmission loss
Lm = Medium loss
FSL = Free space loss
Similarly,

$$Lb\ (dB) = FSL\ (dB) * Lm\ (dB) \tag{2}$$

By considering transmitting and receiving antenna

$$Lt\ (dB) = Lb\ (dB) - Gt\ (dBi) - Gr\ (dBi) \tag{3}$$

Lt = Total transmission loss
Gt = Gain of transmitting aerial pertaining to isotropic aerial.
Gr = Gain of receiving aerial pertaining to isotropic aerial.

System loss is given by eqn. 4

$$Ls = 10 \log (Pt / Pr) \tag{4}$$

Ls = System loss
Pt = Power transmitted to the input of transmitting aerial
Pr = Power received by the output of receiving aerial
Combining relations,

$$Ls\ (dB) = Pt\ (dBm) - Pr\ (dBm) \tag{5}$$

Several environmental losses are absorption loss, reflection loss, scattering of radio waves because of indiscretions in the environmental refractive index. Diffraction loss is due to impediments, radio precipitation is due to rain and snow. Temporal atmospheric sources like fog, cloud, coupling loss, polarization loss, and multipath confrontational impacts. The paper elaborates important results through various sections and subsections with their simulation results like free space loss, rain attenuation, gaseous loss, foliage loss, and loss due to fog, humidity, and cloud.

II. ATMOSPHERIC LOSSES

A. Free Space Loss

In telecommunication, the free space route loss is the loss in the signal strength, which takes place from a line-of-sight route in the air with no obstruction close enough that affects reflection and diffraction. It does not consist of the aerial gain used at transmitter and receiver or whichever loss is related to hardware inadequacies. The waves are not absorbed or reflected in the free space propagation model [3]. Free space route loss is related by the square of the distance between sender and receiver also the square of the frequency of the radio waves. So, this model is referred to as distant dependent as received power depends upon distance and frequency, which obeys power law [4-5]. The transmitted signal mitigates over a distance because the signal is being extended over a big area. This form of signal reduction is called free-space loss. The ratio of power radiated to the power received by an aerial is expressed in terms of free space loss. Free space is an ultimate situation instead of energy consumption or confrontational propagation impacts. Power falls off proportional to the ratio of wavelength over the distance squared and net antenna gain. The model designed is for specific parameters of environment and may not be highly accurate for the general environment. Emission of radio power Pt by an

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omnidirectional aerial in free space give an outcome as a power flux density Po at a distance d is given by eqn. 6.

$$Po = Pt / 4\pi d^2 = Eo^2 / 2\eta o \quad (6)$$

Pt = Transmitter power in watts
d = Distance among sender and receiver aerial in meters
Eo = Electric field amplitude in V/m.
ηo = Free space intrinsic impedance ie. 120 πΩ.
Considering transmitting aerial gain Gt, the power flux density p is given by eqn. 7.

$$P = Pt .Gt / 4\pi d^2 \quad (7)$$

Referring to a getting aerial with an effective aperture area, the obtained response power is given by eqn. 8.

$$Pr = Pe * Ae \quad (8)$$

An effective aperture is given by eqn. 9.

$$Ae = Gr * \lambda^2 \quad (9)$$

By solving equations 7, 8, and 9 we get eqn. 10.

$$P = Pt .Gt / 4\pi d^2 \quad Gr * \lambda^2 / 4\pi \quad (10)$$

$$Pr = Pt\, Gt\, Gr\, \lambda^2 / (4\,\pi\, d)^2 \quad (11)$$

To obtain free space loss using above equations, and assuming gain of antennas equal to unity.

$$Gt = Gr = 1 \quad (12)$$

$$FSL = 10 \log Pt / Pr \quad (13)$$

$$FSL = -10 \log\lambda^2 / (4\pi d)^2 \quad (14)$$

$$FSL= 20 \log 4\pi d / \lambda \quad (15)$$

$$\lambda = c/f \quad (16)$$

$$FSL = 20\log 4\pi *f*d / c \quad (17)$$

$$FSL(dB) = 32.4 + 20 \log (f) + 20\log (d) \quad (18)$$

$$FSL(dB) = 92.4 + 20\log (f) + 20\log (d) \quad (19)$$

An easy method for expressing free space route loss in dB is given by eqn. 20.

$$FSL(dB) = 10\log (Pt/Pr) = 20 \log 4\pi d / \lambda \quad (20)$$

$$FSL(dB) = 10 \log_{10} (4\pi / (c*d*f)^2 \quad (21)$$

$$FSL(dB) = 20 \log_{10} (4\pi/ c*d*f) \quad (22)$$

$$FSL(dB) = 20 \log (f) + 20 \log (d) + 20 \log (4\pi/c) \quad (23)$$

$$FSL(dB) = 20 \log (f) + 20 \log (d) – 147.55 \quad (24)$$

For different aerials we have to consider the gain of the aerial, which harvests below the free space loss equation

$$Pt/Pr = (4\pi)^2 d^2\, Gt\, Gr\, \lambda^2 \quad (25)$$

With the relation among antenna gain and effective area

$$LdB = 20\log (\lambda) + 20\log (d) – 10\log (At.\ Ar) \quad (26)$$

For antenna dimension and dividation, the larger the carrier wavelength, the lower is carrier frequency, and the greater is the free space path loss. The equation 20 reveals relationship between frequency and free-space path loss. The rise in frequency causes an increase in loss measured with 20logf. If we consider the fixed aerial area and gain, the alteration in a loss is measured actually with the reduction in the loss with higher frequencies.

Table 1: Free space path loss

Frequency (GHz)	Path Loss(dB) 100m	Path Loss(dB) 1km	Path Loss(dB) 100km
30	101.98	121.98	141.98
60	108	128	148
120	114.09	134.09	154.09
180	117.54	137.54	157.54
240	120.04	140.04	160
300	121.98	141.98	161.98

From table 1, it is clear that path loss increases as we increase the frequency and distance in the millimeter wave range. Attenuation is less for small distances, so the millimeter wave range frequencies are best suited for LOS communication.

B. Rain Attenuation Loss

Attenuation of excitation is the decrease in magnitude when it dissipates its energy in the space. It is always measured in decibels. Attenuation because of rain may be negative when the gain is positive. Rainfall reduction is a concept concerning the rainfall rate and frequency. It is a true phenomenon which reduces

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propagation at millimeter wave frequencies that require estimating suitable fade reduction techniques [6]. Rain causes attenuation due to absorption and scattering, increases route loss, restricts coverage region, and ultimately reduces performance [7]. A few of the characteristics of rain attenuation are: 1) Rain attenuation decides a quality of communication. 2) Rain attenuation could be measured and predicted and is as old as communication research. The millimeter waves could be absorbed, scattered, depolarized, and also diffracted by shower [8]. Rain attenuation is higher for frequencies above 1GHz and is well correlated at 15GHz and 35GHz. In clear sky conditions, the effect of the environment is minimal [9-10].

Heavy rain impacts communication and concerned applications, mainly in tropical places. Rain produces a Doppler frequency while communication, which affects the carrier frequency shifting and adds extra phase noise. Rain is one of the essential degrading parameters that restrict the outcome of millimeter wave channels, which must be considered while forecasting high-altitude platforms [11]. It attenuates the signal and produces a lot of noise in the destination end. Rain gives a dispersive environment for the communication of radio signals resulting in signal disturbance. The outcome and reliability of radio links were reduced because of rain. The mediocre communication is significant in rain attenuation. There are two ways of air medium, i.e., clear air medium and non-clear air medium. Non-clear air contains rain particles and dust. Hydrometeors mean only water in the environment. Various forms of water linger in the environment like rain, fog, snow, cloud, hail, mist, etc. Radio waves face various types of scattering because of all those elements. The raindrops look like spheres, but the air's force on the base of the drop flattens into oblate spheroids. The very extensively used scattering in communication is Rayleigh scattering. Rain scatter naturally being environment-dependent; values change significantly with time and space. Obtained excitation strength is proportional to transmitter power, the volume of aerial beam juncture, element density, and scattering function. Rain reduces the radio signal's energy because the scattered power at the receiver will be decreased. Non-spherical raindrop greater than 4mm has an impact called depolarization which means the foundation becomes concave. Due to that, various polarizations will communicate through various speeds that contain rain. Hail and snow are responsible for a more significant loss. Cloud causes considerable loss at a greater frequency. At the foundation of the clouds, a melting layer develops, and ice particle melt and becomes rain. The considerably turbulent space has a combination of rain, ice, and snow. Scintillation is a concept of amplitude variation in the waves or any data-carrying signal distributed by a raindrop. Rain attenuation plays havoc in millimeter wave bands. Absorption is because of oxygen and water vapour only. Physical and empirical methods can model rain attenuation. In the physical method, the theoretical or analytical model is suggested.

Physical behavior is involved in the attenuation process, and not all input factors are necessary for analysis. Firms rely on obtained data and their unsuccess to correlate to the physical process present in the empirical method. That provides rainfall rate for the whole continent by separating it into five regions by the cumulative distribution. Data is available from the data collection center or metrological data.

$$A = a\,R^{b} \tag{27}$$

A = Specific attenuation in dB/km
R = Rain rate in mm/hr
a & b = Functions of polarization and frequency
To convert rainfall data into rain rate, separate the available data by observation time.

$$Rd = L * 60 / T \tag{28}$$

Rd = rain rate in mm/hr
L = Highest rainfall interval in mm for time duration Tmin.
The attenuation because of rain is obtained from the ratio of power flux in to the power flux out.

$$\text{Loss} = 10 \log P(0) / P(r) \tag{29}$$

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As the signal travels through the bulk of the shower, its strength reduces exponentially. The shower drops are predicted circular that causes amplitude reduction. The amplitude reduction is because of two energy captivation losses in the raindrops also scattering by water droplets from the occurrence ratio of the signal, as shown in figure 1. Each drop's contributions are different from other drops. Intense rain rate results in link outage if the raindrop dimension reaches half the wave's wavelength in diameter [12].

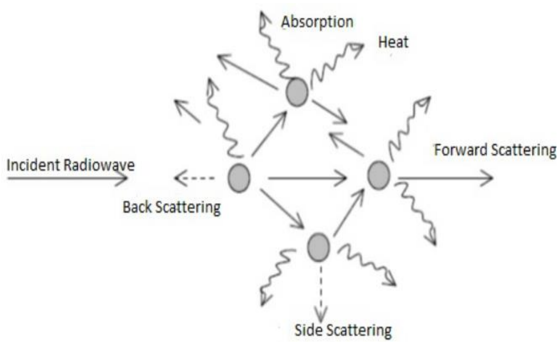

Fig.1. Communication of occurrence radio waves in a rain-occupied medium.

Contributions of the drops are additive. The difficulty of space inhomogeneity of rainfall intensity refers to an in-effect route distance where the route is separated into lesser volumes of spherical water drops. Attenuation could be precisely estimated, if the rain is predicted accurately along the route [13]. As radio waves propagate through that path length, drop, and dispersion occurs on the signal amplitude because of each raindrop called rain attenuation. The entire attenuation in signal propagation is given based on the probability of signal penetrating rain drop Pr(0) and leaving rain drop Pr(r), and the volume of a spherical uniformly distributed raindrop is indicated in figure 2.

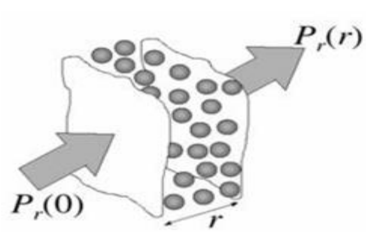

Fig. 2. Volume of circular equally spread raindrops.

$$A = \int_0 \alpha \, dl \qquad (30)$$

Where A = Total attenuation
α = Specific attenuation in dB/km with rain volume in km.

The route is separated into minor rising volumes, and the precipitation is nearly equal. The shower degree in every minor volume is related to a concern reduction called specific attenuation. Theoretical and empirical methods are used to calculate specific attenuation. Because of variation in raindrop size modeling, the raindrop size distribution N(D) is applied with Mie scattering theory to find specific attenuation α in dB/km.

$$4.434 \int \quad \text{ext}(D, \lambda, m) * N(D) \qquad (31)$$

D = raindrop diameter in mm
N (D) = Count of raindrops per m^3 as a function of D.
N (D) can be determined from the drop size distribution model.
m = refractive index of water
λ = wavelength.

This model describes the number and size of precipitation particles which is an essential factor in modeling and finding rain attenuation. Gamma and lognormal distribution are used nowadays, especially in tropical regions. Number and sizes got from the models used to calculate Q extinction, a hypothetical region that explains the radiation being scattered by an element. It depends upon r, λ, R.I. for water m, and permittivity plus the form and dimension of an element. An empirical procedure based upon tentative relation between reduction and precipitation degree R(mm/hr) where the specific attenuation α relies upon the frequency and polarization's rain rate and regression coefficients.

$$= kR^a \qquad (32)$$

k & a = regression coefficient.

It depends upon DSD, temperature, the polarization of radio waves. Attenuation also relies upon a plane of polarization of EM radiations because of the non-circular pattern of raindrops. Vertically polarized wave attenuated less than horizontally polarized. Figure 3 below shows the transceiver with RF modules. The received signal will be processed and digitized using an A/D converter, and output is observed on the PC.

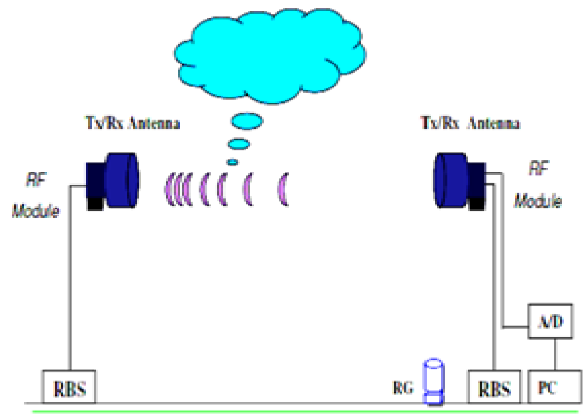

Fig.3. Experimental setup

Table 2: Comparision of rain attenuation [dB]

Sr. No.	Reference No. & Year	Attenuation in dB at frequencies in GHz						
	GHz →	30	35	40	45	50	60	75
1.	[14], 2016	18.2	19	19.8	20	20.2	-	-
2.	[15], 2016	-	-	11.0	-	-	-	16.0
3.	[16], 2019	3	4	5	7	10	22	-
4.	[17], 2022	200	-	220	-	250	260	-
5.	Proposed	1.62	2.0	2.45	2.8	3.15	3.69	4.24

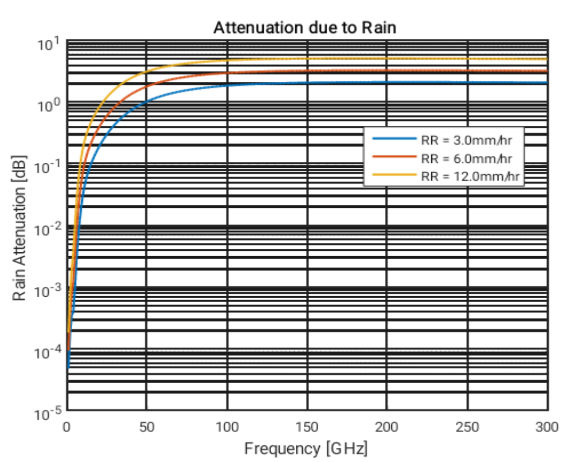

Fig.4. Rain attenuation

C. Gaseous Loss

Radio waves in the millimeter band have large environmental attenuation. The gases in the environment absorb them. They have a small range and are used for terrestrial propagation over around a kilometer. Absorption by environmental gases is an essential parameter throughout the band and rises with frequency. It is higher at some particular absorption lines, primarily oxygen at 60GHz and water vapor at 24GHz. The particle absorption experienced during radio wave transmission in the environment at millimeter wavelength is primarily because of water vapor and oxygen. Attenuation because of absorption due to oxygen and water vapor is usually there and considered in the formulation of overall transmission loss at cycles per second greater than 10GHz [18]. The attenuation of oxygen and water vapor changes with frequency, temperature, pressure, and the environment's mixture [19]. Gaseous absorption because of water vapor and oxygen in the atmosphere causes the resonance up to 300GHz [20].
At frequencies in the wells among that absorption peaks, millimeter waves have small environmental attenuation and greater range. Because of that, different applications use those frequencies. Entire gaseous absorption in the environment Aa (dB) over a route length r_0 kilometer is given by eqn. 33.

$$A_{a} = \int \quad a(r)dr \tag{33}$$

$$\alpha a(r) = \alpha o(r) + \alpha w(r) \tag{34}$$

$\alpha a(r)$ = Specific attenuation in dB/km
$\alpha o(r)$ & $\alpha w(r)$ = Contributions by oxygen and water vapor.

Propagation losses arise when millimeter wave traveling through the environment is absorbed by elements of oxygen, water vapor, and other gaseous of environmental constituents. Those losses are higher at specific frequencies concurring with mechanical resonant frequencies of the gas particles. Figure 5 demonstrates specific gaseous attenuation by water vapor and oxygen which are present at the superficial of earth and mars. It provides qualitative information on gaseous losses and indicates various peaks that arrive because of the captivation of the radio wave by water vapor as well as oxygen. At those frequencies, captivation causes significant attenuation of the radio signal and results reduction in transmission range. A significant absorption peak occurs at 24GHz and 60GHz. The spectral areas among absorption, crests provided windows where transmission is quickly arrived.

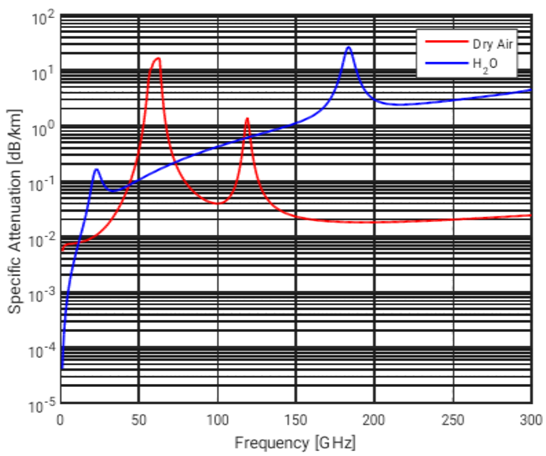

Fig.5. Specific gaseous attenuation

The propagation wells are at 35GHz, 94GHz, 140GHz, and 220GHz. Attenuation by environmental gases relies on frequency, elevation angle, altitude greater than sea level, and water vapor part. It is comparatively less related to rain attenuation. Beneath 10GHz, attenuation because of environmental gases is less than 0.01dB/km, while for greater than 10GHz, attenuation increases for small elevation angles. Water vapor and oxygen are the prime elements to the gaseous attenuation in the frequency band below 30GHz, with the highest arrival at 22.5GHz.

The attenuation due to oxygen absorption is almost analogous for different atmospheric conditions, whereas the attenuation due to water vapor changes with respect to temperature and absolute humidity. The interaction among radio signals and gaseous elements will result into gaseous particle absorption. Precise prediction of environmental attenuation can be obtained by referring to quantum physics and absorption laws.

Absorption attenuation of radio waves causes a quantum level variation in the revolving power of particles. Spectral line absorption arrives when a quantized system such as a particle acts together with an electromagnetic radiation field and transitions between the system's two quantum states. The resonance lines that are most important of water vapor are 22.3GHz, 183.3GHz, and that of oxygen are 57GHz, 63GHz, and 118.74GHz. Summation of all the important resonance lines will give the specific attenuation at a provided frequency [21]. The combined attenuation because of the rain and particle absorption in a dry vacuum with oxygen brings a good approximation of the route loss and route loss exponent [22].

Table 3: Comparision of gaseous attenuation

Sr. No.	Reference No. & Year	Attenuation in dB at frequencies in GHz						
	GHz →	24	30	40	60	125	175	300
1.	[10], 2009	2.5	1.3	-	-	-	-	-
2.	[23], 2015	-	-	0.1	-	1.1	3.3	-
3.	[24], 2017	-	-	-	-	2	22	5
4.	[17], 2022	-	0.1	0.2	10	2	10	10
5.	Proposed	0.12	0.07	0.04	14.9	0.12	4.61	4.43

D. Foliage Loss: -

Establishing a reliable link between antennas of the fixed wireless system is often desired while having path loss due to obstructions existing in the vicinity [25]. Foliage is a significant feature in the degradation of the EM signal. A time-domain channel sounder is used to measure it in the university campus [26]. It is projected that vegetation reduction might be more significant in tropical regions where the vegetation is reasonably compatible or more significant than the wavelength combine with humidity [27]. Knowing and accounting for foliage impacts on communication is vital for future mm-Wave radio system design [28-29]. In spring, attenuation offered by foliage is observed to be more as compared to autumn because of full leave density, attenuation after a few hours of rain decreases as the rain removes the dust particles. Still, water droplets on tree leaves can absorb most of the signal and will cause severe attenuation [30]. Three types of trees are used to measure the dense, medium, and sparse foliage [31]. EM signal penetrates through a few layers of foliage in the millimeter wave range, attenuation due to trees in the urban, suburban, and rural areas leads to foliage loss [32]. The signal attenuation does not increase linearly as the number of trees or length of foliage increases [33]. The graph below shows the impact of foliage loss in the millimeter wave range. In the vicinity of 1km, if we go on increasing frequency, foliage attenuation goes on increasing. At 50GHz, it is 41 dB, but at 100GHz, it is 51dB. Later, it increases at a slower rate. It is essential to consider this loss, while designing a line of sight or near line-of-sight links.

E. Attenuation Due to Cloud, Fog, and Humidity:-

Attenuation by cloud and fog is approximated as cloud attenuation. Droplet formation occurs in the atmosphere near the ground due to condensation of fog, and REAL-Fog tool is used to measure it at ground level [34]. Communication characteristics of standstill water and ice elements that make up environmental haze, fog, and clouds were observed at millimeter wave frequencies [35]. Fog is usually described in terms of visibility and reduction in visibility is given by eqn. 35

$$V_2 = 3.92 / \boldsymbol{\gamma_{op}} \qquad (35)$$

$\boldsymbol{\gamma_{op}}$ = extinction coefficient at optical frequency

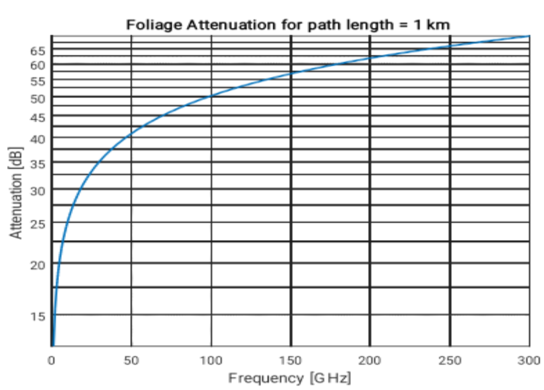

Fig. 6 Foliage attenuation

For V2>1, the atmosphere is defined as hazy. Cloud in general is opaque to visible and IR radiation. Attenuation of EM radiation by water droplets in the cloud is due to both absorption and scattering. The radii of water droplets of cloud are in the range of 1Am to 301Am. The maximum particle distribution occurs around 3 pm to 6 pm. Consequently, clouds will more severely attenuate infrared and visible radiations than RF radiations. Typically cloud thickness ranges from 1km to 6km. Clouds are opaque, so vertical transmittance through such clouds would be less than 0.005%. The cloud water droplets are much smaller than the radiation wavelength in the RF range, so according to Mie theory, attenuation will be much less for visible or IR radiation. Usually, attenuation is expressed as a function of liquid water content in clouds and generally ranges from 1gm/m to 2.5gm/m. The attenuation coefficients of water droplets is given by eqn. 36

$$\gamma = 0.438\ M / \lambda^2\ \text{dB/km} \qquad (36)$$

Where M = Liquid water content in gm/met.

The equation is valid for both cloud and fog in which water droplets are tiny with diameters of the order of 10Pm to 50Pm. The attenuation of RF radiation by clouds is much less than IR radiation. For sensor whose wavelength is more significant than 0.5 cm, the attenuation by cloud is only about 1dB for 1km thick cloud with 1g/m^3 liquid water content. In foggy conditions, water droplets suspended in the air causes attenuation and phase shifts determined by the imaginary and real parts of the refractive index [36]. Cloud attenuation can be measured with empirical models, consisting of cycles per second, elevation angle, and liquid water part as input factors. The simulation results of the proposed model are better than the Dissanayake-Allnutt-Haidara (DAH) model [37]. Comparision is given in table 4. Humidity is one of the elements that characterize the atmosphere which plays a significant role in the propagation of the signal. Water in any state is an obstacle in the link of EM wave where high humidity makes the performances of outage and BER quality slightly worse [14-15]. Humidity is related to the atmospheric water content which affects permittivity and permeability of free space [38].

Table 4: Comparision of cloud attenuation

Sr. No.	Reference No. & Year	Attenuation in dB at frequencies in GHz						
	GHz →	30	35	40	45	50	55	60
1.	[35], 2020	0.52	0.55	0.60	0.65	0.70	0.75	0.77
2.	[17], 2022	4	5.5	10	11	12.5	16	20
3.	Proposed	3.88E-05	5.28E-05	6.9E-05	8.74E-05	0.00018	0.00013	0.000155

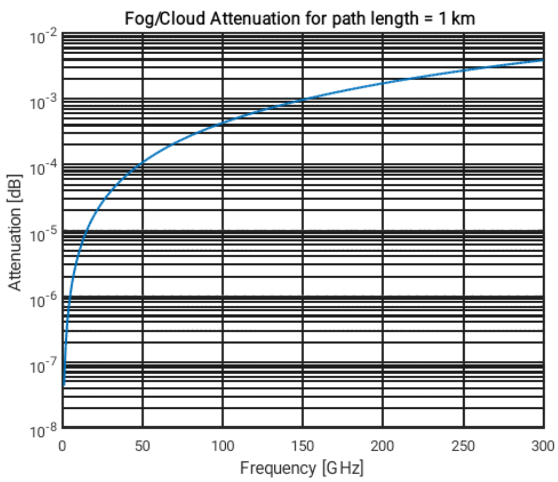

Fig.7. Fog/Cloud attenuation

From figure 7, it is clear that attenuation below 10GHz is minimal and is 0.0001dB at 50GHz and 0.001dB at 150GHz. Attenuation beyond 150GHz rises slowly for the path length of 1km.

III. CONCLUSION

When EM waves travel through the air these are impacted by various environmental parameters and are attenuated more or less severely. The proposed simulation models result into precise estimation of various parameters in millimeter wave range. It estimates free space loss, rain attenuation loss, foliage loss, gaseous loss, loss due to fog, cloud, and humidity and gives very good approximation in the millimeter wave range. Proposed models result into better estimation for tropical regions and are most suitable in millimeter wave range. These models improve quality of reception for indoor and outdoor scenarios in mobile communication system. Models proposed work well and are designed with considering the tropical regions like India.

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