Calculation of Rain Attenuation and Mitigate Using Macroscopic Diversity in Millimeter Wave & THz Radio Wireless Communication Systems

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Abstract

The signal attenuation through rain with various rainfall rates at millimeter wave (30 GHz to 300 GHz) and THz frequency (> 300 GHz) is concentrated in this paper. How to mitigate this rain attenuation is the main objective of this paper. Cellular technology is moving towards its 5th generation (5G) that will employ millimeter wave (mm Wave) frequency and Beyond 5G (B5G) in this THz frequency to meet the requirements of muscular development of interest for high information or data rate communications and swiftly expanding spread of personal communication devices such as smart phones and personal computer. Different atmospheric impairments induce disruption makes this frequency unreliable for short range wireless communication system. Among these impairments, rain attenuation is the most severe one. In this paper various raindrop size distribution model is discussed to calculate the measurement of rain attenuation along with the method of macroscopic diversity is proposed to mitigate this attenuation.

Keywords: - *Rain attenuation, Millimeter, THz, Raindrop size distribution, M-P distribution, Weibull distribution, Diversity*

INTRODUCTION

The expanding request of higher information rates and enormous data transfer capacity in correspondence frameworks makes it basic to utilization of higher frequency.

It may be accomplished very well by utilizing frequencies higher than 30 GHz. In this frequency range some major issues happen because of some atmospheric impairments like retention by the hydrometeors, water fume, and air particles and so forth. In THz infrared (far and near) and beyond that waves range, absorption is extreme to such an extent, that a communication link utilizing these frequencies is practically inconceivable. There is a substantial absorption by the atmospheric oxygen at around 57 GHz to 64 GHz and water fume absorption at around 164 GHz to 200 GHz. Losses because of mist and clouds are not high, but the rain causes noteworthy attenuation, which increases with frequency, and when it rains hard, the radio connection is extremely exposed and gets constriction [1].

THEORETICAL ANALYSIS

A. Free Space Path Loss

The free space pathloss (FSPL) can be defined as the ratio of the transmit power to the received signal power as a function of the transmitter-receiver separation distance due to the signal propagating through vacuum. The free space path loss (FSPL) can be expressed as follows:

$$\text{FSPL (in dB)} = (4\pi d/\lambda)^{2} = (4\pi df/c)^{2} \quad (1)$$

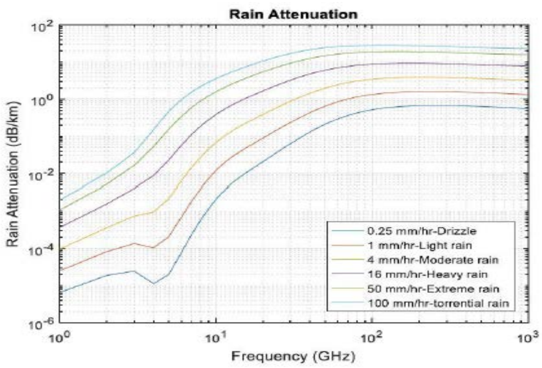
Here it is obvious that FSPL ∝ f 2, resulting a much more severe for mm Wave or THz frequency range.

B. Propagation Loss Due to Rain

The free-space path loss depicts just a piece of signal constriction which happens while going in vacuum. But in practice signals do not propagate through vacuum. Signals collide with particles in nature and lose vitality as they travel along the propagation path. The signal-attenuation varies with different parameters such as temperature, water fume, air molecules and pressure etc. Rain tempted signal-attenuation vigorously for terrestrial microwave radio links which functions at frequencies higher than 10 GHz. Signal constriction by rain increases with increase in frequency. The effect is more severe in case of high rainfall rate. Rain is typically categorized by the rain rate (in mm/hr). The rain rates for various climatic conditions are registered beneath:

Very light raining (Drizzle) < 0.25mm/hr,
Light raining – 0.25 mm/hr to 1 mm/hr,
Moderate raining – 1mm/hr to 4 mm/hr,
Substantial raining – 4 mm/hr to 16 mm/hr,
Outrageous raining – 16 mm/hr to 50 mm/hr,
Heavy raining > 50 mm/hr.

Besides the above, rain attenuation also depends on of the shape of the raindrop, raindrop size distribution, its relative size compared to the RF signal wavelength and the signal polarization. The subsequent figure shows the Rain attenuation in dB/Km over the recurrence band at different rainfall rates as per the ITU suggested model. In general, horizontal polarization denotes the most pessimistic scenario for propagation loss due to rain. Since we are viewed as the most dire outcome imaginable to research the constriction because of rain, the polarisation is supposed to be horizontal and consequently the tilt angle is zero. Furthermore, we are assuming that the signals travel parallel to the ground, the elevation angle is zero. It is deliberated that the range is of 1km [2].



From this figure it is obvious that rain attenuation increases as the frequency increases and is more severe above 100 GHz. Hence it makes difficult for outdoor communication at these frequency ranges. The attenuation level also increases with increase in rainfall rate.

CALCULATION

The rain attenuation (A_{rain}) is predominantly caused by absorption of raindrop in air and can be defined as: [3]

$$A_{rain} = A_{sp\_rain} . r . d/1000 \quad (2)$$

where Asp_rain is the specific rain attenuation in dB/km and can be determined utilizing the ITU model as follows [4]

$$A_{sp\_rain} = k(f).RR^{\alpha(f)} \quad (3)$$

where RR is rain rate in mm/h, k(f) and α(f) are frequency and polarization subordinate constants. In above equation, separation d is in meters and r is a remedy or path reduction factor, which delivers a record of the way that the rain falls just on part of the link separation and can be determined by the following equation [3]

$$r = \left[1 + d/35 \exp(-0.015RR)\right]^{-1}. \quad (4)$$

A. Measuring System

Raindrop size distribution plays a significant role to calculate the measurement of rain attenuation. Rain attenuation is comprehensively dependent on various models of raindrop size distribution. Since we are observing rain attenuation in mm wave and THz frequency as well, the following figure shows a typical rain attenuation measurement system in THz frequency especially operating at 355.2 GHz as given in literature [5]. This entire system mainly consists of transmitter and detector or demodulator. The distance between transmitter and detector is L in meter, which is also known as the channel length. The transmitted signal is attenuated by rain while propagating through the channel. The detector is connected with an interface consisting of rain and temperature sensor to measure the temperature in degree Celsius and the rain rate in mm/hr. This interface is connected with rainintensity thermometer gauge to measure the rainfall intensity. Both the transmitter and receiver utilize a conical horn feeding with an elliptical glass to collimate beams, conferring directivity of 50 dBi. The THz wave is generated utilizing a Phase Locked Oscillator (PLO). It is then amplified with Monolithic Microwave IC (MMIC) raise up to a power level of approximately 1Watt. This amplified signal is then converted to 355.2 GHz using a cascaded Varactor Frequency Doublers (VFDs). The output power is adjusted using an attenuator. Then the THz signal is propagated through the channel. This signal is attenuated by rainfall. This attenuated signal is then driven to the detector utilizing a zero-bias Schottky semiconductor diode acts as a detecting device. The output of Schottky diode is then enlarged using a video amplifier, after that it is driven to a band pass filter (BPF) tuned at 12 KHz frequency to reduce the noise effect. The interface unit then collects data using different sensors and these data are then digitized using ADC. The data logger/controller controls all gadgets, stores the information and exhibit the estimated quantities [5].

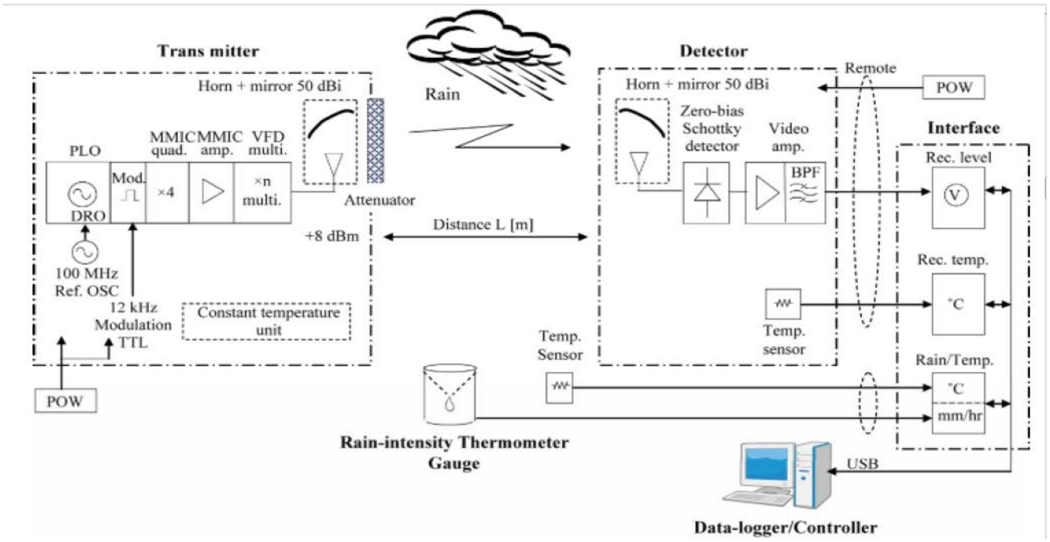


Figure: Terahertz wave propagation measuring system

B. Measuring Rain Attenuation

Rain attenuation is determined by utilizing four sorts of raindrop size distributions and a particular rainattenuation model for use in the forecast technique suggested by ITU-R.

(B1) Raindrop-Size Distributions

In general drop size distribution (DSD) is epitomized by truncated gamma function for diameter as zero to the maximum possible size of rain droplets. The DSD is therefore: $N(D) = N_0 D^{\mu} e^{-\wedge D}$ (5)

Where N_0, μ and $\wedge$ are constants.

Marshall and Palmer [6] proposed the accompanying notable experimental articulation at McGill University in Montre´ al, by accommodating their information and the information of laws and Parsons. Their information was driven in Ottawa, Canada in 1946 utilizing the filter paper strategy. The suitability of this distribution to the investigational arguments was not generally excellent for drops less than D = 1 mm. The basic relationship of MP distribution is of the form X = mYn , where m and n are variable parameters. It is expressed as:

$$N(D)_{MP} = N_0 e^{-\wedge D} \quad (6)$$
$$N_0 = 8000\ m^{-3} mm^{-1}$$

$\wedge = 4.1\ R^{-0.21} mm^{-1}$

Here D is the diameter in unit of mm, and R is the stratiform degree of rainfall in unit of mm/hr.

$$N(D) = (13.5W/\pi a^4)\ (D/a)^{-1.75} e^{-(D/a)^{2.25}} \quad (7)$$
$$W = 8000\ R^{0.846}\ m^{-3} mm^3$$
$$a = 1.3\ R^{0.232}\ mm$$

Litovinov projected a model [8] in 1957 and [9] in 1958 due to Polyakva and Shifrin (P-S) utilizing the Russian information for each of the three sorts of rainfall. This model was additionally designated by Krasyuk, Rozenberg and Chistyakov [10] in 1968 and by University of Tennessee [11] in the year 1975. It was one instance of Gamma Distribution projected by Atlas and Ulbrich [12] in year 1984 as below:

$$N(D) = N_0 D^2 e^{-\wedge D} \quad (8)$$

$R^{-0.5}\ m^{-3} mm^{-3}$ and $\wedge = 7.09 R^{-0.27}\ mm^{-1}$.

N0 and ∧ will differ based on the rain types of defrosting. This formula was derived by considering the way, that a drop is spherical if diameter D < 1 mm and ellipsoidal whose horizontal axis gets compressed as D gets larger.

Sekine and Lind [13] proposed a Weibull distribution in 1982 by utilizing the FOA information (from the National Defence Research Institute) in Sweden:

N(D) = N0 (c/b) (D/b)c-1 e -(D/b)^c (9) $N_0 = 1000\ m^{-3}$

$b = 0.26\ R^{0.44\ mm}$

$c = 0.95\ R^{0.14}$

This distribution is held for millimetre and THz submissions for sprinkle, widespread rain and shower downpour cases. (B2) Calculation of Rain Attenuation To ascertain the rain attenuation utilizing raindrop-size distributions (DSD), rain specific attenuation A in unit of dB/km is determined by evaluating the integration over the entire precipitation-drop-sizes as: [5]

$A = 4.343 \int Q(D,\lambda,m)\ N(D)\ dD$ (10)

where Q is the attenuation cross section which is a capacity of the drop diameter D, the wavelength of the radio-micro wave λ, and the complex refractive index of the water drop m, which is a component of the frequency and the temperature, and N(D) is the drop-size distribution (DSD). The lessening cross section Q is determined by inducing the traditional Mie scattering hypothesis for a plane wave radiation to an engrossing sphere element. As indicated by Hulst [14], the lessening cross-section Q is expanded as:

$$Q(D,\lambda,m) = (\lambda^2/2\pi) \sum (2n+1) \, Re(a_n + b_n) \quad (11)$$

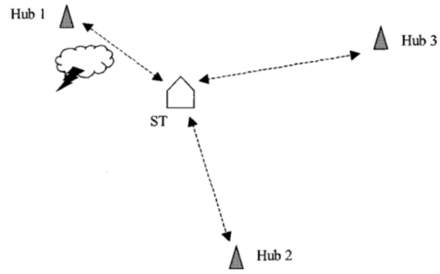
where a_n and b_n are the Mie scattering coefficients, which are complex functions of m, D and λ. The "Mie scattering coefficients" an and bn in above condition denote the influence to the disseminated arena from the multiple poles incited in a sphere, for example a drop of precipitation. The complex refractive index of fluid water m was obtained from examination of Ray [15]. For counting by utilizing the suggested forecast techniques by ITU-R [16], rain specific attenuation γ_R dB/km is attained from the degree of precipitation R mm/hr utilizing the powerlaw equation:

$$\gamma_R = kR^{\alpha} \quad (12)$$

The persistent values for the constants for the coefficients k and α are resolved as functions of frequency, f GHz, which is varied from 1 GHz to 10^3 GHz. This equation is best suited for an elevation angle of horizontal route and the horizontal polarization of radiation.

PROPOSED METHODOLGY

To the best of author's knowledge, no work in the literature focuses on the remission of rain attenuation using macroscopic diversity scheme in mm wave and THz frequency wireless communication. Therefore, for the first time in the literature, novel scheme of macroscopic diversity is proposed to combat with rain attenuation. At high precipitation forces, the event of which is of exceptional enthusiasm for frameworks necessitating high-reliability links, the horizontal structures of rainfall is highly flexible. It is often as possible saw that frequently during a shower, high intensity rain is restricted in a little territory encompassed by a region of more uniform, low rain concentration. Subsequently, in a cellular system under rain with very confined tempests, there is a possibility that a subscriber terminal (ST) getting a vigorously constricted signal from one hub can obtain less attenuated, satisfactory reception from another hub due to the localized property of tropical rainfall. This makes macroscopic diversity show up as a very capable technique for refining link availability and zone coverage. The following figure shows a rough sketch of macroscopic diversity scheme.



Here Subscriber Terminal (ST) can be connected by three different hubs which are separated by large distance. Whenever the tropical rainfall occurs at any particular region under any particular hub, then that link will be disturbed or attenuated. To mitigate this macroscopic diversity is essential to hand over the operation of that particular link to another hub or Base Station (BS). This method is also called hub diversity. If the signal is attenuated coming from the Hub 1 due to rain, then there is a possibility to take over the service by either Hub 2 or Hub 3. But which Hub will be handed over is fully depends on which Hub can transmit the strong signal to ST. This task can be accomplished by continuous monitoring of the links by receiving site antenna at ST. The handover process will be executed by revolving the antenna main beam either electrically or physically.

B. Signal Model

At a point when a client gets provision from a port arrangement, the neighborhood mean signal power at that site from the transmitter of the ith port of the arrangement is demonstrated as below [17]:

$$S_i = [P + G - FSPL - A_{rain}(d_i) + X_i] \text{ dB} \quad (13)$$

Where $1 \le i \le k$, k being the quantity of ports (diversity branches) in the arrangement, di is the separation between the i th port and the user in unit of km, P is the port transmitter power in dB, G is the port antenna gain in dB, FSPL is the free space path loss in dB which is to be determined from equation (1), A_{rain} is the rain attenuation in dB/km which is to be determined from equation (2) and (10), X_i is the arbitrary shadow fading term. All port transmitter powers and antenna gains are expected identical, and every single port antenna have the identical omni-directional outlines in azimuth. The determination of diversity signal Ω is the greatest signal from the serving diversity group port arrangement, i.e.

where an and bn are the Mie scattering coefficients, which are complex functions of m, D and λ. The "Mie scattering coefficients" an and bn in above condition denote the influence to the disseminated arena from the multiple poles incited in a sphere, for example a drop of precipitation. The complex refractive index of fluid water m was obtained from examination of Ray [15].

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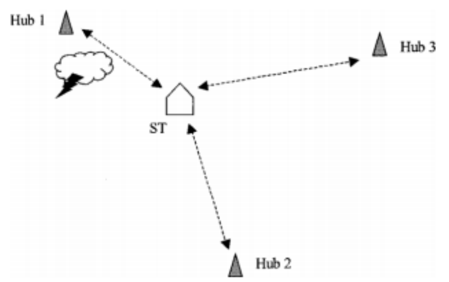

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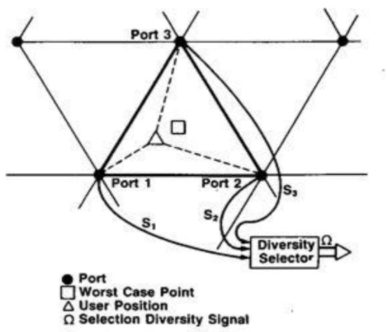
A. Diversity Configuration

Here a three-branch macroscopic diversity configuration is proposed to execute this task depicted in the following figure:



When the user terminal link connected by any port or hub or base station gets attenuated, then the diversity selector selects alternate links for operation. For this selection process the antenna of user terminal continuously monitors the links of each and every port as shown by the dashed (---) lines. Whenever any particular link gets attenuated by rain then the antenna main beam gets rotated to the other port which transmits strong signal according to the diversity selector. Here worst case is that position within a particular cell, where the user terminal finds it difficult to be connected with any port. Here all ports are supposed to have omni-directional antennas, and are at an altitude practically identical to or lower than encompassing structures.

B. Signal Model

At a point when a client gets provision from a port arrangement, the neighborhood mean signal power at that site from the transmitter of the ith port of the arrangement is demonstrated as below [17]:

$$S_i = [P + G - FSPL - A_{rain}(di) + X_i] \text{ dB} \quad (13)$$

Where $1 \leq i \leq k$, k being the quantity of ports (diversity branches) in the arrangement, di is the separation between the i th port and the user in unit of km, P is the port transmitter power in dB, G is the port antenna gain in dB, FSPL is the free space path loss in dB which is to be determined from equation (1), A_{rain} is the rain attenuation in dB/km which is to be determined from equation (2) and (10), Xi is the arbitrary shadow fading term. All port transmitter powers and antenna gains are expected identical, and every single port antenna have the identical omni-directional outlines in azimuth. The determination of diversity signals Ω is the greatest signal from the serving diversity group port arrangement, i.e.

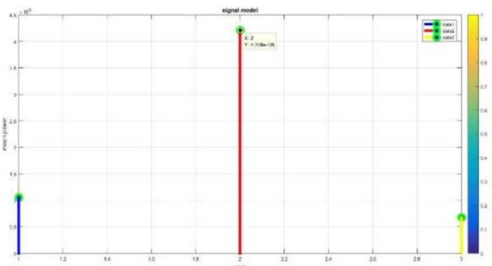
$\Omega = \max\{S1, S2, S3\ldots Sk\}$ (14)

In this way, the diversity mechanism model depends upon the determination of the most extreme serving port signal and hence the user terminal is able to obtain a reliable signal in devastated rain attenuated environment also. In this way we can combat the rain attenuation and mitigate that using macroscopic diversity scheme in millimeter and THz wave radio frequency cellular wireless communication systems.

SIMULATION RESULT

Since we are considering identical omnidirectional antenna for all ports therefore, all ports will have same antenna gain G in dB. Here it is assumed as 2dB. Port transmitter power can be written as $P=kd^2$ from Friss transmission equation. Here random shadow fading term is considered as 12dB. Carrier frequency is considered here as 30 GHz and velocity of light is $c= 3*10^8$ m/s. Frequency and polarization subordinate constant k(f) and α(f) are taken as arbitrarily as 0.005 and 0.002 respectively. Distance between client and ports d and rainfall rate RR are varied according to the port position. Here it is considered three distinct ports. According to the above data a simulation result is given using MATLAB as below:

Port	d (m)	RR (m/hr)
1	500	0.05
2	1000	0.01
3	400	0.02



Selected port = 4.2088e+05 Reliable connection established

Therefore, it is seen from this simulation result that port 2 is selected due to maximum received power according to the given signal model as operated by the Diversity Selector. Therefore, the reliable link is established and rain attenuation can be mitigated.

CONCLUSION

Here in this paper calculation of rain attenuation has studied in mm Wave and THz frequency radio wireless cellular system. It has also shown that rain attenuation increases due to increase in frequency and rate of rainfall as well. Hence it is a severe problem for mm wave and THz frequency wireless system, especially for short range outdoor communication. Hence to mitigate this problem a method is proposed based on diversity scheme known as macroscopic diversity or hub diversity which we have studied in this paper and we can see from this scheme that we can establish an alternate link and can get less attenuated robust signal from this method.

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