Rain attenuation and depolarization prediction techniques engineering essay

Engineering

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Abstract—Satellite communication plays a major role in today's communication across the earth. It is more advantageous compared to terrestrial mode of communication. In wireless communication one needs to use higher frequencies in order to increase the bandwidth and get much wider bands. But the increase of frequency will lead to many disadvantages which will degrade the performance. In this project we have tried to predict the losses due to rain using standard models and simulating them in MATLAB software and analysing various associated features with them. Rain attenuation, gas attenuation and depolarization are the major losses along earth station and satellite communication.

Index Terms—Rain fall Rate, Rain Attenuation, Depolarization, Carrier-to-Noise ratio, Ku-band.

IntroductionThe atmosphere surrounding our earth causes several problems on satellite communication. It becomes a serious issue when we operate in the bands above 10 GHz say Ku(10-18 GHz). The three major factors which effects the communication are: 1) Frequency: as it increases the attenuation increases. 2) Elevation angle: If it is high then the length through which the signal passes in the atmosphere becomes low and it results in less attenuation compared to lower angle of elevation. 3) Climate of the location of earth station: If the sky at the earth station is clear then we won‘ t be facing much attenuation. Sometimes even if the sky is clear we face attenuation due to the absorption of signals by the atmospheric gasses like oxygen, water vapor. In satellite-earth communication, precipitation can cause much attenuation particularly in systems operating above 10 GHz which can cause performance degradation. There are three forms of precipitation : a.) ice b.) water c.) gaseous. However the attenuation that is caused by ice and fog is very much less compared to rain when we operate in Ku band. There are various models developed to calculate losses that occur due to rain attenuation, gaseous attenuation and depolarization. RAIN ATTENUATIONAs mentioned above rain is the most serious atmospheric problem. Rain is not homogeneous both in time and space. The link-margin which is distributed for rain-fade, link distance of link for communication, and the climate of terrain all are used for determining the availability of rain. It is basically the time-percentage so that the available fade margin of rain doesn’t exceed. Rainfall can be measured both by empirical and non-empirical models by collecting data over a period of time. Empirical methods won‘ t give us good results as rain is totally dependent on nature and is mostly random in nature. Main problem of rain is that it absorbs the signal and reduces the strength of the carrier. It is mainly dependent on the frequency being used. It normally shows up when we operate above 10GHz. Raining on the dish antenna directly will lead to absorption of signals at higher frequencies. It can even cause depolarization. Attenuation due to rain is dependent on rain rate which is rate at which rain water gets accumulated at earth-station. In calculations we measure rain rate in milimeters per hour. MODELSIn order to understand the applications of rain fade analysis we need to understand the area of link-availability with its relation with link-budget. At first, any communication link design must provide that for what time-percentage the operation of the link continues. Then allocation of availability is done for different sources which can result in link outages, for e. g interference, rain-fades, and failing of hardware components. When we know the allocation of availability of rain, rain fade models can be used to decide that what level of fade will not exceed for probability same as the rain availability allocation. Than the link budget incorporate the value of rain-fade, and resultant link-budget is used to find either the maximum link distance or other important parameter like for e. g, the transmit power required. We use rain rate of interest and regression coefficients to calculate the specific attenuation. Different rainfall rate is used by different models and in equations used for modelling, they use the same regression coefficients for a specific-attenuation. In order to measure the specific attenuation for a given rate of rain, we use the operation frequency for selecting the right linear regression coefficients and if needed then interpolate them. Log scale for frequency is used for interpolation of the coefficients and the values for ‘ k’ and linear scale for the values of ‘ α’. These are dependent on polarization used and frequency. Following expressions are used for calculating final coefficients, which account for the polarization and elevation-angle . Where, is the elevation-angle, is the tilt angle for polarization (for horizontal 0., 45 for circular, and 90 degrees, for vertical). T1: ESTIMATING SPECIFIC ATTENUATION USING REGRESSION COEFFICIENTSFrequency(GHz)kHkV

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01681. 2171. 2200. 07510. 06911. 0991. 065300. 1870. 1671. 0211400. 350. 310. 9390. 929Source: Table 1 , courtesy of the ITU. From the coefficients we can see that the horizontally polarized signals have greater effect of rain than vertically polarized signals. This is true because of general vertically elongated shape of raindrops. The effect on circularly polarized signals is somewhere in middle of the two. Even though there are many models to predict, most useful of them with better prediction statistics close to experimentally determined results are the following two models: ITU-R modelCrane modelITU-R ModelThe ITU model calculates the rain statistics via data fileswhich are indexed by latitude/longitude for giving more clear estimate for rain statistics rather than looking at the concept of rain region. The model divides rain on the earth on the basis of rain rate(denoted by A to P excluding I and O) aside from providing the probability of the given rain-rate being exceeded. Most areas of India fall in region K of it. The ITU model firstly provides only the 0. 01% rain statistics and then-after uses an adjustment factor for predicting rain fade depth for different probabilities. As the atmosphere above the earth surface is not homogeneous, the slant path attenuation is not a function of link distance. The first step of calculating hR below is for geosynchronous orbit (GEO) i. e for geo-stationary satellites The advantage of using them is that the Doppler shift they encounter is minimal and thereby the corresponding higher orbital altitude produces a much longer time delay and more free-space loss than that encountered for lower orbits. In the first step we compute the expected height of rain cell as a function of rainfall rate and latitude. fig 1: diagram for attenuation predicationThe method is as follows: S1: Calculate the rain height, hR(in km) as in [1]hR = hs + 0. 36where hs(in km) is height of the earth-station above mean sea level. In next step we calculate the elevation angle using earthstation and satellite geometry: fig 2: geometrical deduction of elevation angleWhere re is the radius of the earth (6378km). h is the height of satellite above the centre of the earth and 🗘 is the elevation angle. Using Sin law: = = Which gives rs = central angle is: Ψ = (sin(π/2 + θ) - θ)to find θ: Cos(Ψ)= cos(Le)cos(Ls)cos(ls-le) + sin(Le)sin(Ls), where earth station latitude is Le, le is the longitude of earth station, Ls is the latitude of sub-satellite, ls is the longitude of sub-satellite. As now we know the central angle, then distance of slant-path and elevation angle can be calculated using: rs = h√(1+(– 2()cos(Ψ))and, cos(θ) = S2: For 🗘 🖸 5🖮 compute the Ls(length of slantpath), below the rain height from: else, if 🗘 ■ 5🖮, the below given formula is used: S3: Determine the horizontal projection, LG(in km), of the slantpath length from: LG ● Lscos🗘S4: Determine the rate at which rainfall falls, R0. 01,(in mm/hr) exceeded for 0. 01% of basis of average year (where integration time = 1 minute) using ITU maps as in [2] and below in T2. T2: 0. 01% RAIN FADES FOR RAIN RATE DATA OF ITUS5: Determine the specific attenuation, █R(in dB/km), using the frequency-dependent coefficients given in T1 on page 2 and the rainfall rate, R0. 01, calcualated from S4, by using:█R ● k (R0. 01)✔S6: Now use the following formula for measuring the horizontal reduction factor, r0. 01, for 0. 01% of the time: S7: Determine the vertical adjustment factor, v0. 01, for 0. 01% of the time: if 🚭 🗛 🗘, otherwise, If | 🛪 | ■ 36🖮, ☐ ● 36 – | 🛪 | degreesElse,☐ ● 0 degreesS8: Determine the effective length of path (in km) by using the formula: LE ● LR ⬤0. 01S9: The predicted attenuation which is exceeded for 0. 01%

of an average year is: A0. 01 ● █R LE dBS10: The last step is to deduce exceeded estimated attenuation(in dB) for various percentages of a year(Ap) on an average basis, varying from 0. 001%-5%, is determined via attenuation exceeded for 0. 01% of an year on average basis: If p 📀 1% or | 🛩 | 📀 36🎹: 🚲 ● 0If p < 1% and | 🛩 | < 36🎹 and 🗘 📀 25🎹: Then 🚲 ● –0. 005(| 🛩 | – 36)Otherwise: 🚲 ● –0. 005(| 🛩 | – 36) + 1. 8 – 4. 25 sin 🗘We see that the expected net attenuation on an earth–space path is dependent on frequency, angle of elevation and rain rate (availability) only. When testing this model in MATLAB for Ahmedabad at a frequency of 13 Ghz, where hs is about 0. 05 km and lat/long of 23oN/72oE θ obtained as 65o , with rain rate of 45, the attenuation came out to be around 19. 2 dB. Crane modelEven though this model provides rain data for different rain probabilities, unlike ITU it doesn’t provide availability adjustment factor. Also the regions denoted are different from ITU(alphabets are from A to but different letters for different regions compared to ITU). The difference lies in that for the desired availability, the corresponding specific rain rate must be used. Crane uses data for height of rain cell which is the function of latitude and probability. Maximum regions of India fall in D region of crane model. In first step it takes rain heights for 0. 001% rain fade and 1% rain fade(as in T4) for a given latitude and then follows a way for calculating the logarithmic interpolation over availability as follows: h001 : rain height for p = 0. 001%, h1 : rain height for p = 1%HR(p) = h1 + ln(p)T3: RAIN RATES FOR CRANE MODEL FOR DIFFERENTPROBABILITIES AND RAIN REGIONST4: RAIN CELL HEIGHTS FOR CRANE MODEL FORDIFFERENT LATITUDESThe approximate path length in rain is: d = 2(HR - HS)/(√tan(ζ) + tan2(ζ) + 2(HR- HS)/Re)where, effective rain cell height is denoted by HR, the effective station height is HS, ζ is the angle of elevation, Re is the 4/3 of the earth radius(approx. 8500km). The formula for rain attenuation on terrestrial path determines the horizontal path attenuation as: and, δ(RR)(depends on rain rate) (in km) = 3. 8-0. 6ln(RR)where, d(km)= link-distancey= α[(0. 83-0. 17ln(RR))/δ(RR)+0. 26-0. 33ln(RR)]z = α.(0. 026-0. 03ln(RR))Due to rain the total slant path attenuation is as follows: As=(L/d)Attenuationwhere, L=√[(Hs-Re)2sin2(ζ) +2Re(HR-HS)+HR2-HS2]-(HS+Re)sin(ζ)One drawback of global Crane model is that its only holds true for up to 22. 5-km link distance, on the other hand we can use ITU model up to 60km. Using the crane model for distances more than 22. 5 km will give us unpredictable results. Implementing both the models in same conditions will give almost same results. DEPOLARIZATIONRain depolarization is calculated via same techniques applied to rain attenuation. The difference lies in examining depolarization, we assume the rain drops to be oblate spheroids. The raindrop is generally at a random orientation with respect to the wave propagation direction. The orientation specified is denoted by q angle, between vector of propagation and the axis of symmetry of rain drops. The component which is vertical is parallel to the minor axis of the rain drop and therefore has less water content and it’s the case of quite opposite for the horizontal component. As a result, there will be a difference between the attenuation and phase shift of each electric field component. This is known as differential attenuation and differentia phase shift and they leads to depolarization of the signal. For a Geostationary earth orbiting satellite transmitting a linear polarized wave, horizontal polarization is the case where electric field is parallel to Earth’s equatorial plane and vertical polarization is where its Earth’s electric field is parallel to the Earth’s polar axis. The main purpose of polarization is to bring down the interference between different signals belongs to different frequencies and introduce frequency reuse but when the signal passes through atmosphere, sometimes an additional orthogonal signal might get generated which leads to the effect of depolarization and interference. The cross-polarization discrimination (ratio of received co-polar and generated cross-polar component) in dB due to rain is given by: $XPD = U - V\log A$Where A in dB is attenuation due to rain and U (dB), V(dB) are the coefficients determined empirically where$U = 30 \log f - 10 \log(0.5 – 0.4697\cos 4\zeta) – 40 \log(\cos(\theta))$Where ζ is polarization angle. CARRIER-to-NOISE RATIOA very effective method of determining the quality of the signal is link budget or C/N. Under some given conditions we calculate the C/N ratio and then compare it with the threshold clear sky C/N for the type of signal that we are sending.. Threshold is defined based on details of coding, modulation and multiplexing used with the signal. For different uses, C/N is different, e. g for digital signals C/N correlates to bitrate and bit-error rate, for video signals it correlates to on-screen video quality, for audio it correlates to audio quality.

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C/N(Link Budget) = EIRP + G/T +228. 6 -space loss –atmospheric loss –misc loss –bandwidthWhere, EIRP stands for Effective isotropic radiated power: i. e effective strength of transmitter. It is the sum of transmitting amplifier power and gain of the transmitting dish(changes as per size of the dish), G/T : gain of the receiving dish(G) (expressed as $G = 4\pi Ae/\lambda$ where Ae is aperture length of antenna) minus the system noise temperature(T) of the receiving electronics(determined by LNA electronics and noise environment). 228. 6: decibel equivalent of physical constant(Boltzmann’s constant) that comes in due to conversion of noise temperature(in Kelvin) to noise figure(in dB), Space loss: amount of power lost because the signal travelling the distance, Atmospheric loss: power lost due to absorption.(generally around 5 dB for Ku-band), Misc loss: due to slight mis-alignment of dish, or in polarization orientation, losses in connection between antenna and amplifier(usually form 0 to few dB), Bandwidth used: noise power bandwidth of the environment. (N = kTsBN where Ts is system temperature). Among the above mentioned parameters, only G/T and EIRP can be changed effectively as losses are generally frequency dependent. Space-loss is given as = 32. 4 + 20log(h) +20log(f) where h is satellite height from earth, f is in MHz. Miscellaneous losses include Feeder loss, misalignment loss, etc(generally small). Atmospheric losses include absorption, rain attenuation. These are generally very less and vary as per environment. results and analysisAfter performing all the calculations and implementing the models and equations in MATLAB, we do the analysis of the results obtained. Also we try to think the established conventions from a different perspective. First of all we should argue that when so many losses and factors affect Ku band than why to use it. After all we have read enough that frequencies lower than Ku band are less affected by atmospheric effects. The reason is that more frequency means more power to transmit the signal. But then the attenuation also increases with frequency increase. So why then use it. The answer is that power takes more weightage than attenuation and other effects. At the same time, adequate measures are need to be taken to keep attenuation phenomenon in check. In fact, UHF band frequencies are immune of the atmospheric phenomenon. PlotsIn this section, we will look and observe different plots simulated with the help of MATLAB based on the information presented in this report. fig 3: plot of rain rate (R0. 01) for 0. 01% fade v/s attenuation(A0. 01). We see from the fig 3 that as rain rate increases the attenuation also increases. For R0. 01 = 30 mm/hr, A0. 01 = 8. 78 dB for ITU model which reaches gradually to 42. 04 dB for R0. 01 = 100 mm/hr while the same for Crane is 8. 05 and 27. 5 dB respectively for θ = 65o and f = 12 GHz. We see that the attenuation difference between that predicted by ITU and Crane is very small(around 3 dB). This tells that for distance up to a fair range, both models are almost equally efficient. Fig 4: attenuation(A0. 01) v/s XPD(dB)Here we can observe from the fig 4 that as rain attenuation increases the cross-polarization discrimination decreases. For R0. 01 = 30 mm/hr, A0. 01 = 8. 78 dB, Xpd = 29. 68 dB for ITU model which reaches gradually to 16. 4 dB for R0. 01 = 100 mm/hr while the same for Crane is 8. 05 and 16. 08 dB respectively for θ = 65o and f = 12 GHz. We see that the XPD difference between that predicted by ITU and Crane is very small which again proves that for distance up to a fair range, both models are almost equally efficient. This also proves that these models are very good estimates of rain attenuation and polarization prediction. Moving to another point, if we look at the variation of ‘ k’ and ‘ α’ we can say that kH has slightly higher value than kv and same is the case with ‘ αH’ and ‘ αv’. Also ‘ k’ value increases with increasing frequency. The coefficients suggest the rain has more effect on the horizontally polarized signals than compared to vertically polarized signals. This is true because of general vertically elongated shape of raindrops. Circular polarized signals lie somewhere in between these two plarizations. When it comes to C/N, we can see that rain is not a major source in itself to downgrade it, but it can significantly increase the system noise temperature which in turn downgrades the ratio. Amount of depolarization goes up with increase in frequency and rain rate. It also increases with increase in amount of rain absorption. CONCLUSIONThe modelling of rain-fades for satellite links is very much alike to that for terrestrial links, although a bit more tedious and complex, since the applied model should must hold true the variation in density of rain with altitude. To lower the effect of attenuation and other atmospheric phenomenon amounting to losses, Path diversity (two Tx-Rx pairs)can be used for mitigation of rain fadeIn Crane model we use 4/3 of Earth’s actual radius because of the atmospheric effects and the large distances at which satellites are located from earth-stations. Also, the two models discussed hold true for Geo-stationary satellites(fixed elevation angle). The overall expected attenuation on an earth–space path ends up being dependent on angle of elevation, rain-rate (availability), and frequency only. With increasing use of satellite communication in DBS-TV(direct broadcast satellite-TV) etc, and VSAT(very small aperture terminal). and other economic boom coming in this field has created the need to consider the improvement in satellite communication in different frequency bands. AcknowledgmentWe duly acknowledge our BTP mentor Prof. Deepak Ghodgaonkar and BTP co-ordinator Prof. Manish Gupta for guiding and helping us in gathering the relevant data and resources for the project,

implementing it, schedule it in a structured and proper manner thereby helping us in preparing this report.