Propagation Effects on Microwave Signal due to Atmospheric Gases

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Abstract

For wireless communication systems, the channel is free space or atmosphere. An atmosphere consists of many particulates such as gases, rain, fog, snow, hail, temperature, etc. Due to all these parameters the signal strength will be attenuated. Especially at microwave frequencies, more amount of energy of microwaves is lost or attenuated by these parameters. At low atmospheric pressures, the attenuation and phase dispersion on the wideband signals will be more and results the signal distortion. Due to this signal distortion, more bit errors will occur and causes the presence of inter symbol interference (ISI) in the received signal. In this paper, we have obtained the attenuation due to various atmospheric parameters such as water vapor, oxygen, clouds, hydrostatic. Also we evaluated mean estimation error by using the approaches like single line (LOS) estimation; 2-line estimation and Mean line estimation. It is shown that, with mean line estimation approach, the estimation error is low as compared with other approaches.

Keywords:Signal attenuation, Inter Symbol Interference, Mean Line estimation, Phase dispersion, Atmospheric parameters.

1. Introduction

In Previous days the frequency range of 50 to 70 GHz has been avoided because of more attenuation of signal strength due to presence of gases in the atmosphere.The research is in progress for how to use these frequency range in digital wireless apllications. The main advantages of using the 50-70 GHz frequency range is, wide bandwidth, presence of high attenuation which helps in reducing the interference between the adjacent cellular channels, and aids in preventing the unauthorized users from intercepting the transmission. The major problems that arises for a signal in the range of 50-70 GHz band are attenuation and absorption of the signal strength due to rain drops[1] and gases, dispersion of phase by the atmospheric gases like Oxygen and water vapor. The molecules of gases like Oxygen absorbs more energy from the EM waves due to its magnetic dipole moment and causes phase dispersion of EM waves. In a wideband digital signals, the phase dispersion will cause the parts of digital waveform to fall into neighboring time slots which constitutes an interference called inter-symbol interference (ISI). The effect of different layers of atmosphere on the images obtained by the Synthetic Aperture Radar satellite (Terra SAR-X) can be evaluated and also the attenuation due to rain can be calculated[2].

2. Propagation Effects on Microwave Signal

The atmospheric phenomena like absorption and attenuation will occur mainly at low altitudes, preferably in the troposphere. To calculate the attenuation due to the atmosphere, there are several models but they are mostly regional dependence. When the EM wave travels through the atmosphere, there is an interaction mechanism between the EM waves and gases like Oxygen and water vapor which results molecular absorption. The density of water vapor will vary depends upon the season and region where as oxygen volume ratio in the gases is quite stable. Using the ITU (International Telecommunication Union) gaseous absorption model, the attenuations due to both compositions along horizontal and vertical paths are computed. Under clear weather, the dominant attenuations at SHF bands come from atmospheric absorption. These losses are negligible at the lower frequencies (less than 3 GHz). As the radio signal frequency increases, the absorption by atmospheric gases increases significantly. The attenuation is severe for high frequencies due to rain and other precipitation products such as snow, ice, fog, hail, etc[3]. When the waves incident on water drops, the drops will absorbs and scatter the energy into different directions. Due to this absorption and scattering, the signal attenuation will increase exponentially with increase in frequency. The attenuation coefficient of the rain drops is also strongly dependent on the rainfall rate. Clouds and fog can be described as collections of smaller rain droplets. The atmospheric attenuation is mainly dependent on elevation angle, temperature, refractive index, frequency and it can be represented in terms of the total water content per unit volume based on Rayleigh Approximation[4]. For the analysis of attenuation in medium, the attenuation due to the oxygen, water vapor for vertical and horizontal path, and also for different elevation angles is evaluated. The specific attenuation due to oxygen is given by[5]

$$\gamma_o = \left[7.19 \times 10^{-3} + \frac{6.09}{f^2 + 0.227} + \frac{4.81}{(f-57)^2 + 1.50}\right] f^2 \times 10^{-3} \frac{dB}{km} \quad -(1)$$

Where f is frequency in GHz. The specific attenuation due to water vapor in the horizontal dependence is given by

$$\gamma_w = \left[0.067 + \frac{3}{(f-22.3)^2 + 7.3} + \frac{9}{(f-183.3)^2 + 6} + \frac{4.3}{(f-323.8)^2 + 10}\right] f^2 \rho 10^{-4} \quad -(2)$$

in dB/km. where ρ is the density of water vapor in g/m^3, 'f ' is the frequency in GHz. In this paper we selected a maximum value of density 12 g/m^3 and average value of 7.5 g/m^3

To consider the attenuation factor for rain fall the total specific attenuation rate, γ_R, is defined as a function of rain fall rate, R, as

$$\gamma_R = kR^{\alpha} \quad in \ \ dB/km \qquad -(3)$$

In above equation the two coefficients a & k are the functions of elevation angle and signal frequency. For the attenuation consideration due to fog, it is expressed in terms of the total water content per unit volume based on Rayleigh Approximation[6]:

$$\gamma_c = K_l M \qquad dB/km \qquad -(4)$$

Where:

Kl: specific attenuation coefficient $[(dB/km)/(g/m^3)]$ γc: specific attenuation (dB/km) within the cloud

M: liquid water density in the cloud or fog (g/m^3)

3. Mean Line Estimation Approach to Atmospheric Effects for Wave Propagation.

For the improvement in the estimation accuracy "Mean line estimator (MLnE) logic is proposed. This method improves the estimation accuracy by the consideration of n-line observations in comparison to 2 line system. The mean line estimation method is outlined below. The high accuracy scientific applications like studies of weather, sea level, plate tectonics, ice dynamics, climate, crustal deformation, etc, will utilize the microwave signals transmitted by the Reference Systems. For transferring of data the system uses two carrier frequencies such as 1.575 GHz (L_1) and 1.228 GHz (L_2). Receivers for high accuracy tracking of these three carriers are commercially available at relatively low cost. To analyze microwave signals these estimator logics are used. Generally the radio waves can propagate trans-horizontally through different transmission modes apart from line of sight propagation[7]. The modes of transmission and propagation mechanism of EM waves depend upon radio frequency, climate, distance, time percentage of interest and path topography. Wherein, during the transmission process of such microwave signal the atmospheric effects such as refraction, dispersion and attenuation are observed. Wherein conventional coding based on correlative estimation, the received coded signals are observed for relative estimation. In the conventional method the received signals are tuned to a particular frequency of L_1 and L_2. But in real time processing the signals are not concentric at the tuned frequency because of refraction. These refracted signals will arrive the receiver through the different paths called multipath and also these signals will have different measuring levels. The signal traveling through these paths are affected by multiple atmospheric factors and hence the probability of estimation degrades in such coding by different level of atmospheric dispersion. Atmosphere-induced propagation path delays and un-modeled multipath are major contributors to the measurement error[8]. The changes of humidity distribution are associated with storms, clouds and convection. The signals will be scattered into multiple short form signals out of the fundamental frequency due to refraction and attenuation by the atmospheric parameters. Wherein conventional approach it is observed that the dispersion is considered in horizontal (L_1) and vertical (L_2) direction, the two signal are deviated in multiple direction. The circular polarization is used for transmission of signals and only the delay of a vertical and horizontal polarized component is observed. The horizontal and vertical delays can differ depending upon elevation angle of the propagation path, the orientation of the hydrometers, and the polarization sensitivity of the receiving antenna[9]. Wherein the L_1 carrier is affected more strongly and the L_2 carrier is affected less strongly. In the conventional method L_1 and L_2 are processed form a linear combination of the L_1 and L_2 phase measurements to cancel the dispersive ionospheric propagation effect on the signal[10]. The probability of estimation is then given by;

$$L_c = \frac{f_1^2}{f_1^2 - f_2^2} L_1 - \frac{f_1^2}{f_1^2 - f_2^2} L_2 \quad - \quad (5)$$

Wherein L_1 and L_2 are the carrier phase measurements, L_c is the ionospheric free phase measurement and f_1 and f_2 are the carrier frequencies. Wherein such conventional system it is observed that the estimation signal are considered by L_1 and L_2 lines only but the multipath signals are not considered.

The scattered isolated signal is propagated through isolated M distinct sub channels with the a frequency response[11] of

H_m (f), m = 0,1,………, M-1.

The set of M signal simultaneously effected at a given time instant T is defined by a_n = [a_0(T),a_1(T),………,a_{M-1}(T)] ,where F = 1/T is the dispersion rate. By considering all the line parameters the observed signal at the receiver can be defined by

$$s(kT_c) = \sum_{m=0}^{M-1} \sum_{n=-\infty}^{+\infty} h_m\,(kT_c - nT)x(nT) \quad - \quad (6)$$

Where signal received by the kth channel at T_c delay is the sum of all dispersed signal h_m phase deviated from original frequency x at nT by a factor of kT_c. Therefore estimation probability of the proposed system can be defined by

$$L_c = \frac{\left(L + s(kT_c)\right)}{M} \qquad - \quad (7)$$

where $s(kT_c)$ is the multiple path observation obtained from the diffracted paths, L is defined as the observatory factor defined by prior equation. Therefore to derive the final estimation, the observation factor Lc is used.

4. Results and Discussion

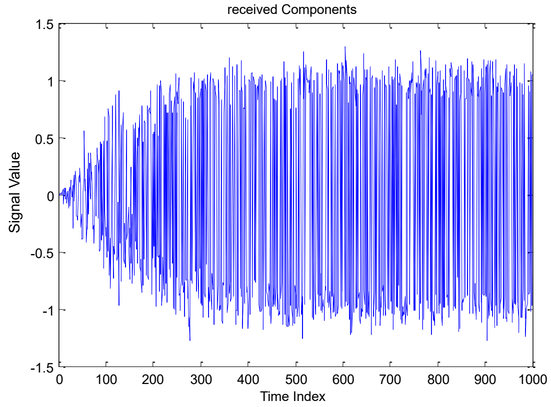

Figure 1: Signal Dispersion signal at the receiver

For the evaluation of the developed approach a simulation observation is modeled where the dispersed signal at the receiver is observed as shown in figure 1.

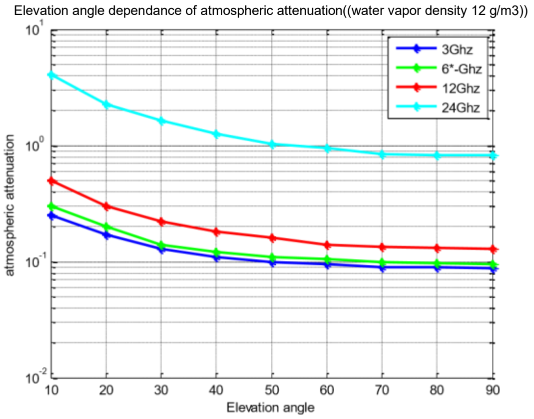

Figure 2: Elevation angle dependence of atmospheric attenuation for 3,6,12 and 24 GHz (water vapor density 12 g/m^3)

Figure 2 shows the dependence of atmospheric attenuation on elevation angle for different frequencies due to water vapor density 12 g/m^3. The atmospheric attenuation is observed to be very high at 24GHz than the lower frequency. So attenuation is least compensated at such frequency.

Elevation angle dependance of atmospheric attenuation((water vapor density 7.5 g/m3))

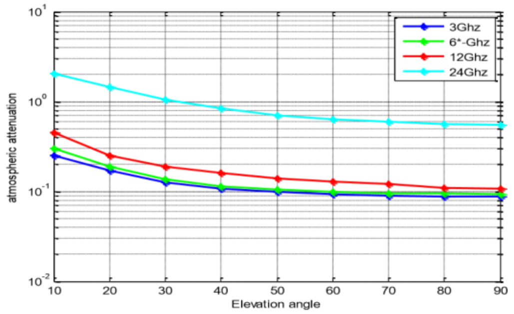

Figure 3: Elevation angle dependence of atmospheric attenuation for 3,6,12 and 24 GHz (water vapor density 7.5 g/m^3)

Figure 3 shows the dependence of atmospheric attenuation on elevation angle for different frequencies due to water vapor density 7.5 g/m^3. The atmospheric attenuation is observed to be very high at 24GHz than the lower frequency.

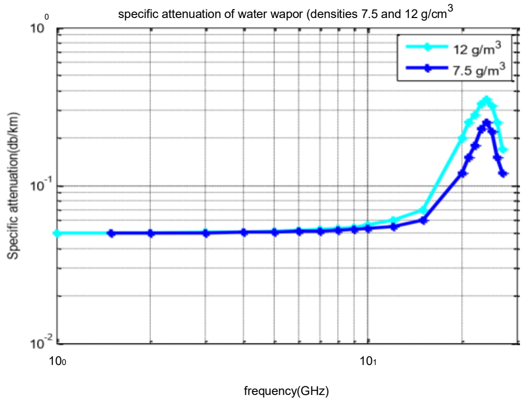

Figure 4: Specific attenuation due to water vapor (densities 7.5 and 12 g/m^3)

Figure 4 shows the specific attenuation due to water vapor density for various values of frequencies. For the simulation purpose we have selected two densities of water vapor such as 12 g/m^3 and 7.5 g/m^3. From this result it can be observed that, the specific attenuation increases with water vapor density. The specific attenuation due to water vapor is maximum at 22 GHz.

5. Conclusions

In summary, atmospheric delays induced by dry air are relatively large and they are depending on slowly varying pressure fields which are relatively easy to model. The humidity is the major contributor of delay in the signal. The delays induced by the atmospheric humidity can be as large as 50% of the dry air. These delays are highly variable and are difficult to model because of geometric effects. The other parameters of atmosphere such as hydrometeors will induce delays less than 3% as compared with the delays induced by the humidity and dry air. Because these highly variable constituents are difficult to quantify, range errors from these constituents cannot effectively be modeled. In this work we focus on developing an approach towards communication mode to evaluate the propagation effect of microwave signal in various atmospheric conditions. The effect of ionospheric condition for the multiple frequency signal transmission is observed over isolated frequency. We proposed Mean line estimation logic for signal estimation in the microwave range. The proposed mean line estimation logic improves the estimation probability resulting in higher estimation accuracy in microwave system. It is shown that, for a given communication system the fraction of offered data rate is improved with the usage of proposed mean line estimator in comparison to conventional correlative estimation logic. It has been observed that, an improvement in the estimation performance in the range of microwave frequencies with mean line estimation logic as compared with correlative logic.

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