Effect of Atmospheric Turbulence on Wireless Optical Link

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Abstract

In wireless optical communication system, communication is obtained between receiver and transmitter in free space. The major challenge for wireless optical communication system is the free space atmospheric attenuation and scattering caused by Scintillation and aerosol particles (Rain, fog, drizzle and haze). Analysis has been done for the statistical data and then compared with real time data to obtain the refractive index variation due to atmospheric attenuation which cause high impact on wireless optical link design.

Keywords:

Wireless Optical Communication (WOC), atmospheric attenuation, refractive index, Bit Error Rate (BER), Scintillation, Signal to Noise ratio [SNR]

1. Introduction

In wireless optical communication links, atmospheric turbulence causes fluctuations in both the intensity and the phase of the received light signal, impairing link performance [1]-[3]. Turbulent fluctuations in the wind velocities in the upper atmosphere mix layers of differing temperatures, densities and water vapor content causes change in refractive index [1]-[13]. Thus the index of refraction of each level of the atmosphere fluctuates.

Refractive index variations which gives micro-thermal fluctuations and cause diffractive and refractive beam perturbations and consequent distortions are collectively called turbulence [2]. The effects may be characterized as amplitude scintillations, coherence degradations, beam spreading, beam steering or bending etc.

Wireless optical communication is very sensitive to atmospheric conditions and meteorological effects, such as rain, drizzle, fog, haze, turbulence and thermal expansion of atmosphere, all of them cause fading effect in the received signal[6]-[7].

2. BASIC CONCEPT

2.1. Atmospheric attenuation

Atmospheric attenuation results from absorption and scattering of light signal by aerosols and gas molecules in the atmosphere. Transmittance is a function of the distance as given by BEER relation[4] :

$$\tau (d) = P (d) / P (0) = e^{-\sigma d} \qquad (1)$$

where:

- $\tau(d)$: Transmittance at the distance ‘d ’of the transmitter
- P(d): Power of the signal at a distance ‘d’ of the transmitter
- P(0): Emitted power
- σ : Specific attenuation or extinction coefficient per unit of length
-d: distance between Transmitter and Receiver

A. 2.2. Rain attenuation

B. Attenuation due to rain, independent of the wavelength, is a function of the precipitation intensity R (mm/h) according to the following relation [3]:

$$Att_{rain} = 1.076 * R^{0.67} \text{ (dB / km)} \quad (2)$$

C. Scintillation

Random interference with the wave front can cause peaks and dips, resulting in receiver saturation or signal loss [4]. "Hot spots" in the beam cross section can occur of the size about 3 cm for an 1550 nm beam 1 km away [11]. WOC systems operate horizontally in the atmosphere near the surface, experiencing the maximum scintillation possible. Scintillation effects for small fluctuations follow a log-normal distribution, characterized by the variance, σ_i, for a plane wave is given by the following expression [5]:

$$\sigma_i = 1.23 C_n^2 k^{7/6} L^{11/6} \quad (3)$$

Where k = 2ϕ/λ.

The expression for the variance for large fluctuations is as follows [5]:

$$\sigma_{high}^2 = 1.0 + 0.86(\sigma^2)^{-2/5} \quad (4)$$

Obviously shorter wavelengths would experience a smaller variance.

Rayleigh scattering coefficient or extinction coefficient can be written by the following relation [7]:

$$\sigma \cong \beta_n = \frac{3.91}{V}\left(\frac{\lambda_{nm}}{550}\right)^{-Q} \quad (5)$$

where:

- V is the visibility (km)
- λ is the wavelength (nm)
- Q is the size distribution of the diffusing particles:

= 1.6 for strong visibility (V>50 km),

= 1.3 for average visibility (6<V<50 km),

= 0.16V + 0.34 for visibility (1 km<V<6 km)

= V - 0.5 for visibility (0.5 km<V<1 km)

= 0 for low visibility (V<0.5 km)

3. SNR and BER CALCULATION

Both SNR and BER are used to evaluate the quality of optical communication systems. BER performance depends on the average received power, the scintillation strength, and the receiver noise. With appropriate design of aperture averaging the received optical power could be increased as well as reducing the effect of the scintillation [9][10]. The SNR with turbulence in terms of the mean signal and noise intensity Io and ⟨In⟩, is given as[8]:

$$SNR = \frac{I_0}{\langle I_n \rangle} = \frac{\langle A_0^2(r) \rangle}{\langle A_n^2(r) \rangle} = [\langle \varepsilon^2 \rangle]^{-1} \quad (6)$$

For weak turbulence model, ε is very small thus it is given as:

$$\chi = \ln(1+\varepsilon) \approx \varepsilon \quad (7)$$

With this approximation SNR can be written as:

$$SNR = [\langle \chi^2 \rangle]^{-1} = (0.31 C_n^2 k^{\frac{7}{6}} L^{\frac{11}{6}})^{-1} \quad (8)$$

Including the beam spreading effect, the effective SNR is defined as:

$$SNR_{eff} = \frac{SNR}{\left[1+1.33\sigma_{lnIR}^2\left(\frac{2L}{kw_L^2}\right)^{5/6}\right]+F\sigma_{lnIR}^2 SNR} \quad (9)$$

Where $W_L = (W_{O2}+L^2\theta^2)^{0.5}$ is the spot size of the phase front at range L in the absence of turbulence, Wo is the minimum spot size in transmitter, θ is the beam divergence angle. F is the aperture averaging factor defined as the ratio of the normalized intensity variance of the signal at a receiver with diameter D to that of a point receiver [12]:

$$F = \frac{\sigma_{lnIR}^2(D)}{\sigma_{lnIR}^2(D=0)} \quad (10)$$

In our model we have assumed that the surface area of the photo detector is large enough, therefore F is small, thus is negligible. The effective SNR is reduced as given below [14]:

$$SNR_{eff} = \frac{SNR}{\left[1+1.33\sigma_{lnIR}^2\left(\frac{2L}{kw_L^2}\right)^{5/6}\right]} \quad (11)$$

For WOC links with on-off keying (OOK) modulation scheme the Bit Error Rate (BER) is considered [8] as:

$$BER = \frac{exp^{(-SNR/2)}}{(2\pi SNR)^{0.5}} \quad (12)$$

4. Real Time Calculation

Fig.1and 2, shows the Refractive Index variation which has been analyzed for the year 2010 and 2011, for the all four type of temperature variations (Extreme maximum, average maximum, average minimum and extreme minimum) with respect to Vellore atmosphere [ref; IMD] . Here Pressure variations are considered as constant [15].

Fig.3 and 4 shows the Refractive index variations which has been obtained by considering both the temperature and pressure variations at 500m height using real time data from [15] National Atmospheric Research Lab , Gadanki , South India.

These refractive index values fluctuate with time due to fluctuations in temperature and pressure which termed as Atmospheric Turbulence which results change in direction of propagation.

$$N = (7.9 \times 10^{-2} P/\lambda T^2) \quad (13)$$

Where

- P in atmospheric units and
- T in degree Kelvin

. The first order change in refractive index is

$$\Delta N = (7.9 \times 10^{-2} P/\lambda T^2)\,\Delta T \quad (14)$$

The Optical Path Difference (OPD) generated by a cell of length L due to temperature variation would be

$$OPD = 2L\,\Delta N = 2L\,(7.9 \times 10^{-2} P/\lambda T^2)\,\Delta T \quad (15)$$

A small temperature fluctuation of the order of a one tenth of a degree might generate strong wave front perturbations over a propagation path of few hundred meters.

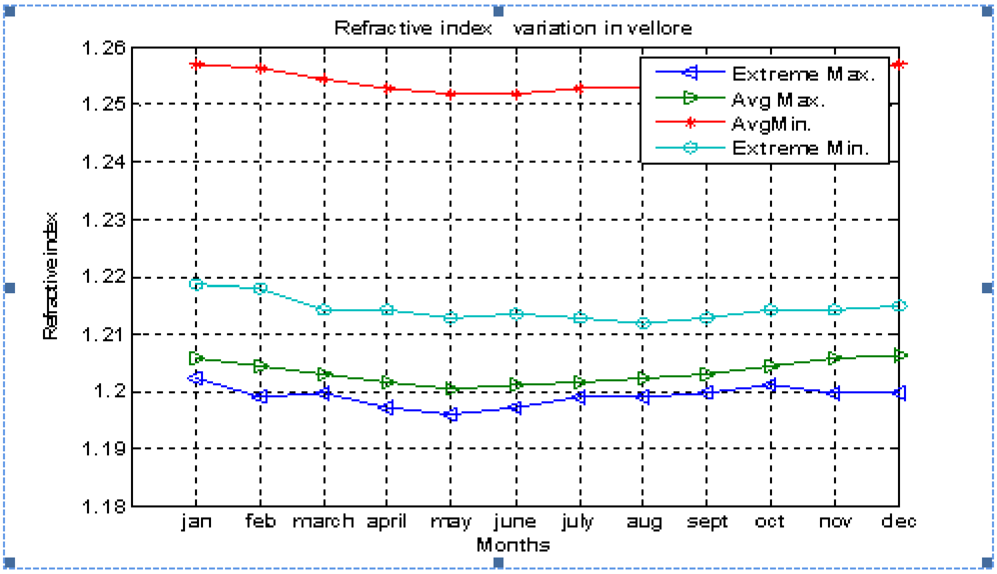

Fig.1 Refractive Index variation [2010]

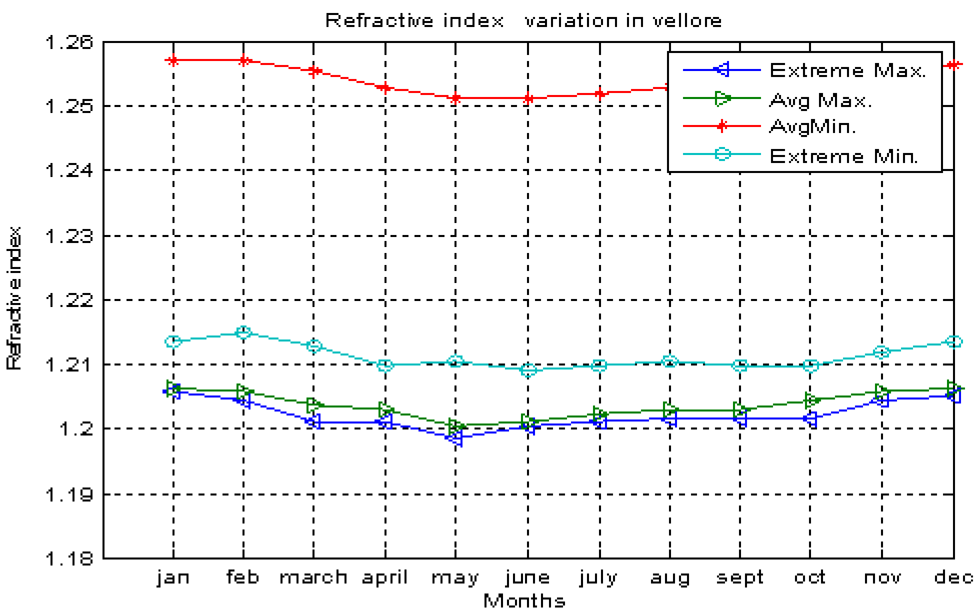

Fig.2 Refractive Index variation [2011]

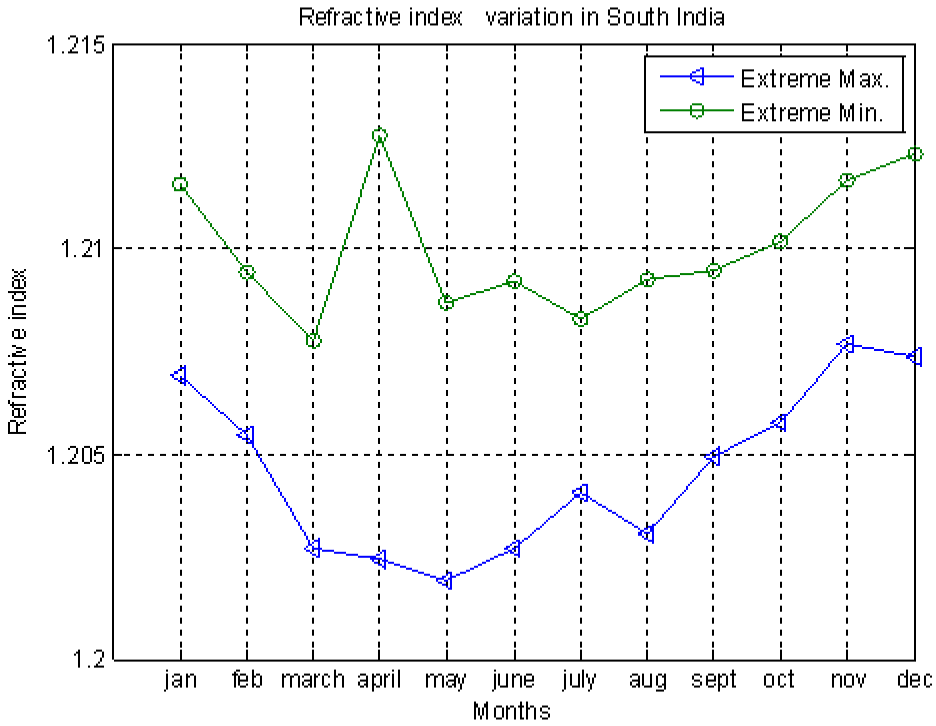

Fig.3 Refractive Index variation Vs Temperature

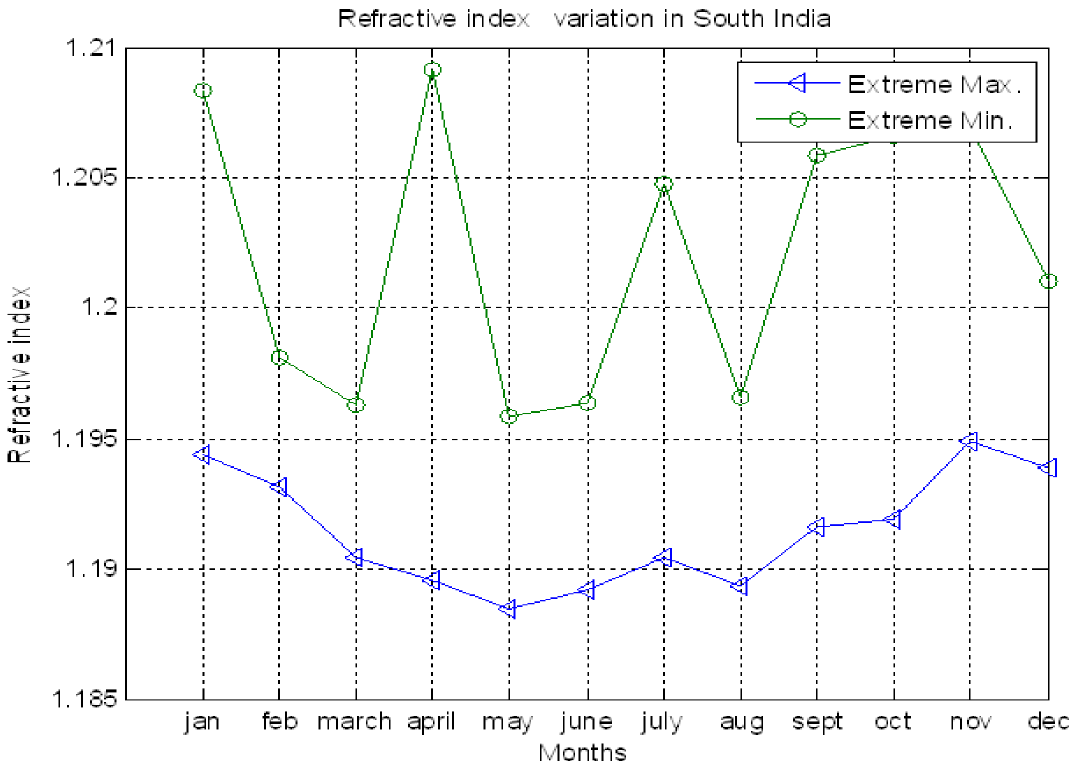

Fig.4 Refractive Index variation Vs Pressure variation

5. CONCLUSION

The effect of atmospheric turbulence on refractive index variation has been analyzed and it has been observed that turbulence leads to annihilation of the signal transmitted in the WOC link. The Refractive index variation calculations are made for south Indian region for IMD data and also for the laboratory data [National Atmospheric Research Lab, Gadanki] results in South Indian Region [15]. This result will be useful for the analysis of atmospheric attenuation on wireless optical link in this geographical region and it can be considered for the WOC link design in South Indian Region.

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