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Atmospheric Turbulence Effect on Free Space Optical Communications

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Abstract: This work discusses the effect of atmospheric turbulence on wavelengths transmission in free space. The Rytov variance calculated for plane and spherical waves, were Rytov variance of spherical waves less than from plane waves, on the other hand in spherical waves the values of wavelength 1550 nm less than from the other wavelengths. Scintillation attenuation was calculated depends on Rytov approximation for wavelengths (1550, 850, 633, 532) nm, scintillation attenuation values of the wavelength 1550 nm less than from the other wavelengths. The wavelength 1550nm has a good signal to noise ratio(S/N) from the other wavelengths. The distance between the transmitter and receiver links was (0-1000) m, we take into account the refractive index structure parameter at different turbulence (10^{-16} low, 10^{-15} medium, 10^{-14} high) $m^{-2/3}$ for all calculations.

Key words: Rytov variance, Rytov approximation, atmospheric turbulence.

I. Introduction

Free-Space Optical (FSO) links involve the transmission, absorption and scattering of light by the Earth's atmosphere. The atmosphere interacts with light due to the composition of the atmosphere which, under normal conditions, consists of a variety of different molecules and small suspended particles called aerosols.

This interaction produces a wide variety of optical phenomena:

- Selective attenuation of radiation that propagates in the atmosphere,
- Absorption at specific optical wavelengths due to the molecules,
- Generation by scattering (the sky blue color, the red sunset, etc.) or by radiative emission of an optical beam comparable to noise at the source of perception contrasts loss. This loss is all the more important since the distance is large,
- Scintillation due to the variation of the air's refractive index under the effect of temperature (stars twinkle) [1]. Refraction occurs as a result of propagation effects through the layered quasi-homogeneous structure of the atmosphere as a gaseous continuum, causing optical rays to propagate not long the straight radio paths but curve slightly toward the ground [2]. Atmospheric turbulence generated by the temperature different between the earth surface and the atmosphere. The temperature $T(b)$ in degree kelvin, and pressure $P(b)$, in Pascal's, as a function of the altitude b , in meters, for the first 11km of the atmosphere can be determined from the following expression [3]

$$T(b) = 288.15 - 65.45 \times 10^{-4} \cdot b$$

$$P(b) = 1.013 \times 10^5 \cdot \left[\frac{288.15}{T(b)} \right]^{5.22} \quad (1)$$

II. Atmospheric Turbulence

Optical turbulence occurs when turbulent winds in the earth's atmosphere mix the always-present vertical moisture and temperature gradients caused by the sun's heating of the earth's surface. This creates irregularities in the refractive index of the atmosphere in the form eddies, or cells, called "optical tubules" [4]. The reason of optical signal scintillation is simply illustrated in fig.(1). The scintillation is caused by the turbulent cells, which are areas with variant refractive indexes [4].

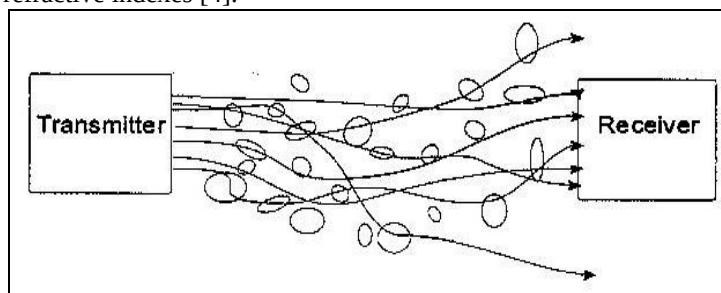


Fig. (1) Atmospheric transmission media with turbulent cells

III. Rytov Variance

The Rytov variance is a measure of the strength of scintillation, ray propagation through a turbulent atmospheric medium will experience irradiance fluctuations called scintillations [5]

The relation between refractive index structure parameter C_n^2 and the relative variance of optical intensity σ^2 was set by Rytov as [6]

$$\sigma^2 = K.C_n^2.k^{7/6}.L^{11/6} \quad (2)$$

Where C_n^2 is the refractive index structure parameter, k represent the wave number ($2\pi/\lambda$), and L is the distance between the transmitter and receiver of the optical wireless, and K is a constant equal to

$$K = \begin{cases} 1.23 & \text{for plane wave} \\ 0.5 & \text{for spherical wave} \end{cases} \quad (3)$$

A plane wave model is used for starlight and other exoatmospheric sources; a spherical wave model is used for a small – aperture source within or near the turbulent atmosphere.

The scintillation index σ^2 [dB²] can be expressed by the following relation [7]

$$\sigma^2 = 23.17.k^{7/6}.C_n^2.L^{11/6} \quad (4)$$

Where, k (m⁻¹) is the wave number

L (m) is the length of the link

C_n^2 (m^{-2/3}) is the structure parameter of the refractive index, representing the turbulence intensity.

Scintillation peak to peak amplitude is equal to $4\sigma^2$ and attenuation related to scintillation is equal to $2\sigma^2$, the relation for the turbulence attenuation α_{rytov} can be written as [7]

$$\alpha_{\text{rytov}} = 2.\sqrt{23.17.k^{7/6}.C_n^2.L^{11/6}} \quad (5)$$

For a practical FSO system (plane wave) with weak and symmetrical atmosphere turbulence the log irradiance variance is given by [8] :

$$\langle \chi^2 \rangle = 0.31C_n^2.k^{7/6}.L^{11/6} \quad (6)$$

Therefore, the noise source is the atmosphere turbulence

$$\langle \chi \rangle = -\ln(1 + \varepsilon) \quad (7)$$

$$\varepsilon = A_n(r) / A_0(r)$$

Where $A_n(r)$ is the amplitude of noise, $A_0(r)$ is the amplitude of laser beam in the atmosphere without turbulence.

The SNR in terms of mean signal and noise signal intensity I_0 and $\langle I_n \rangle$, respectively is given by:

$$SNR = \frac{I_0}{\langle I_n \rangle} = \frac{\langle A_0^2(r) \rangle}{\langle A_n^2(r) \rangle} = [\langle \varepsilon^2 \rangle]^{-1} \quad (8)$$

For weak turbulence mode, ε , is very small thus eq. (7) is given as [9]:

$$\langle \chi \rangle = -\ln(1 + \varepsilon) \approx \varepsilon \quad (9)$$

With the approximation in eq. (9) the SNR is written as

$$SNR = [\langle \chi^2 \rangle]^{-1} = (0.31C_n^2.k^{7/6}.L^{11/6})^{-1} \quad (10)$$

Without the above approximation eq. (9) is written as

$$\langle \chi \rangle = -\ln(1 + \varepsilon) \approx \varepsilon = (e^{\chi} - 1) \quad (11)$$

For weak turbulence ($C_n^2 \leq 10^{-14} \text{m}^{-2/3}$), the SNR is given by eq. (10), when the turbulence is not weak ($C_n^2 \geq 10^{-14} \text{m}^{-2/3}$), the relationship between the SNR and χ is much more complicated. But by using the

Taylor series for function $f(\chi) = (e^{\chi} - 1)^2$ and with some simplification, eq. (8) can be written be approximated to [9]:

$$SNR = \frac{1}{\langle \chi^2 + \chi^3 + \dots \rangle} \approx \frac{1}{\alpha \langle \chi^2 \rangle} \quad (12)$$

When $1 \leq \alpha \leq 2$ and represents the strength of scintillation (for worst case $\alpha = 2$)

IV. Results and Analysis

Rytov variance for plane and spherical waves calculated at different atmosphere turbulence ($10^{-16} \text{ m}^{-2/3}$ low turbulence, $10^{-15} \text{ m}^{-2/3}$ medium turbulence and $10^{-14} \text{ m}^{-2/3}$ high turbulence) for wavelengths (1550, 850, 633, 532) nm, all simulation were run in matlab. Fig. (2) shows Rytov variance at 1550 nm for propagation distance (0-1000)m.

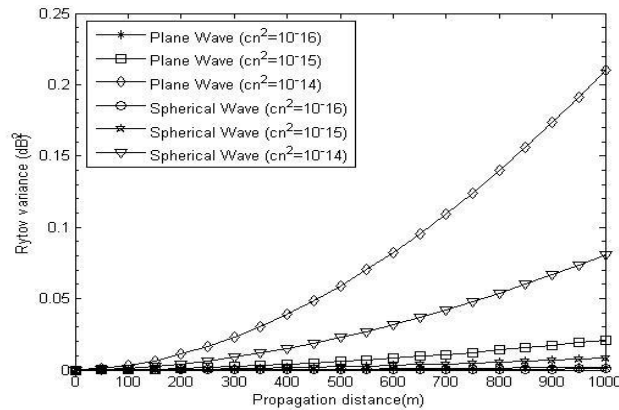


Fig. (2) Comparison Rytov variance for plane and spherical waves at different atmospheric turbulence to wavelength 1550nm

According to the results obtained the Rytov variance has big values for plane comparison with spherical waves at high turbulence the difference is 0.1294 dB at distance 1000m.

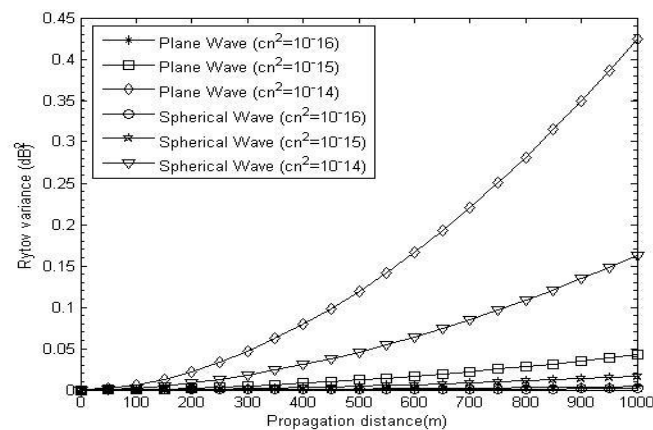


Fig. (3) represent Rytov variance for 850nm, the results shows the difference between plane and spherical waves in high turbulence is 0.2609 dB at distance 1000 m.

Figure (4, 5) illustrate Rytov variance for visible wavelengths (633, 532) nm which has high values of variance comparing with IR wavelength, the difference between plane and spherical waves was 0.3679 dB at parameters ($\lambda=633 \text{ nm}$, $C_n^2=10^{-14} \text{ m}^{-2/3}$, $L=1000 \text{ m}$). But for 532nm the difference was 0.4507 dB at the same parameters.

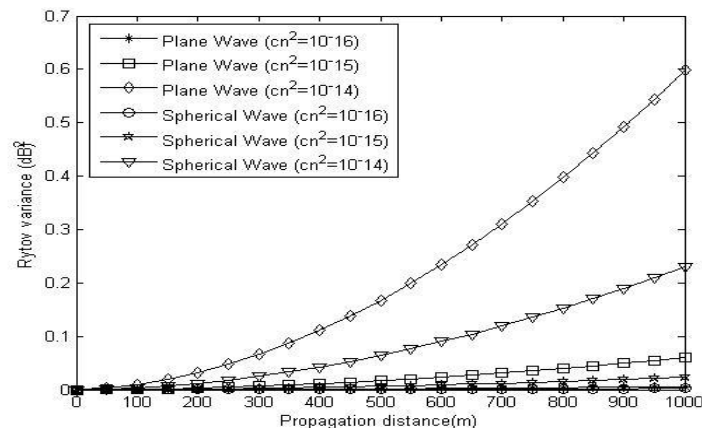


Fig. (4) Comparison Rytov variance for plane and spherical waves at different atmospheric turbulence to wavelength 633 nm.

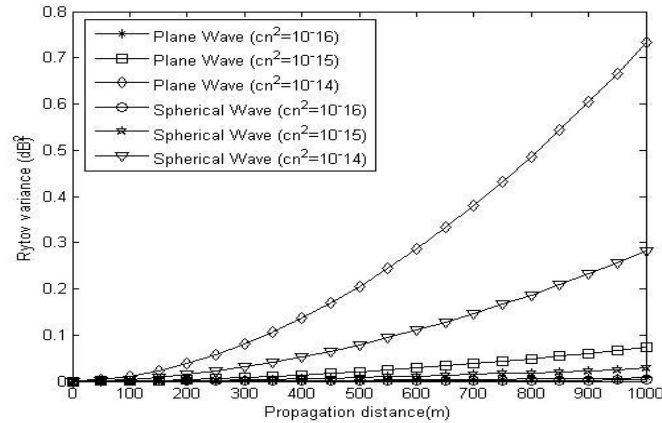


Fig. (5) Comparison rytov variance for plane and spherical waves at different atmospheric turbulence to wavelength 532 nm.

The scintillation attenuation calculated depends on Rytov approximation to wavelengths (1550, 850, 633, 532) nm. The refractive index structure parameter was $(10^{-16}, 10^{-15}, 10^{-14}) \text{ m}^{-2/3}$ and the link distance (0-1000) m. The results obtained in fig. (6) for wavelength 1550 nm at different refractive index structure parameters, The scintillation attenuation at high turbulence was 3.8721 dB

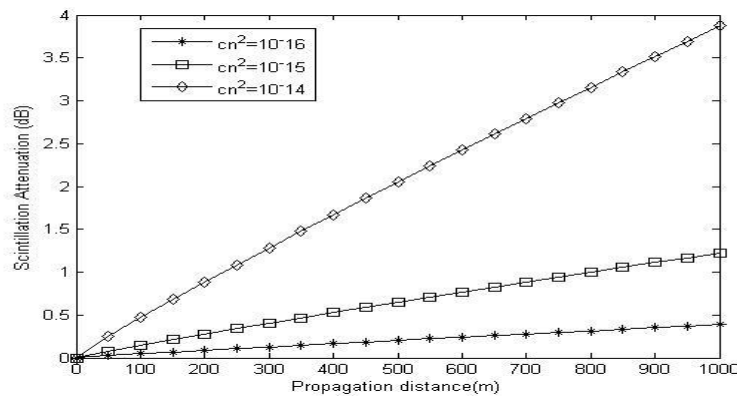


Fig. (6) Comparison of Scintillation attenuation (dB) at different turbulence to wavelength 1550 nm

The scintillation attenuation by Rytov approximation at (850) nm illustrated in fig. (7), the value of attenuation for high turbulence ($Cn^2 = 10^{-14}) \text{ m}^{-2/3}$ was 5.4972 dB, this value bigger than (1550) nm about 1.6251 dB.

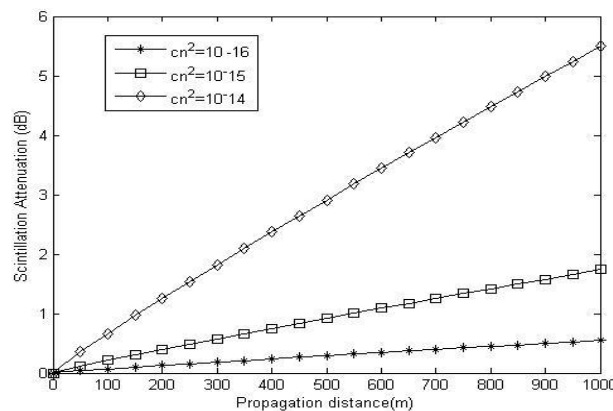


Fig. (7) Comparison of Scintillation attenuation (dB) at different turbulence to wavelength 850 nm

The same calculations for visible wavelength (633, 532) nm performed as shown in figures (8, 9), where the scintillation attenuation is 6.5286 dB at parameters ($\lambda = 633 \text{ nm}$, $Cn^2 = 10^{-14} \text{ m}^{-2/3}$, $L = 1000 \text{ m}$, while 7.2253 dB for 532 nm at the same parameters

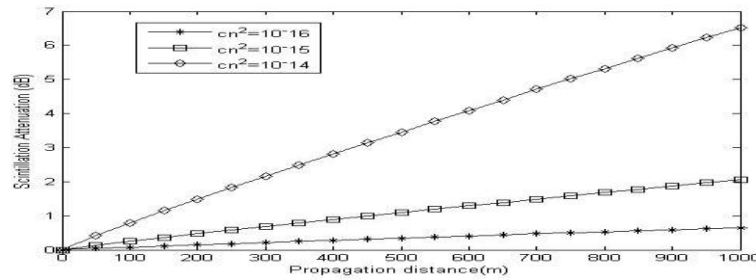


Fig. (8) Comparison of Scintillation attenuation (dB) at different turbulence to wavelength 633nm

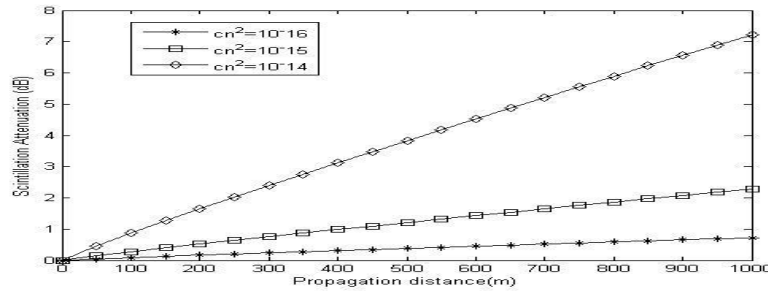


Fig. (9) Comparison of Scintillation attenuation (dB) at different turbulence to wavelength 532nm

When we calculate SNR at different turbulence, we obtain characteristic as shown in figure (10). We observe the effect of the turbulence affects various the wavelengths, at the visible wavelength the effect of the turbulence is very close. Either at infrared wavelength, the wavelength 1550nm was less affected by turbulence and it had large S/N as shown in fig. (10).

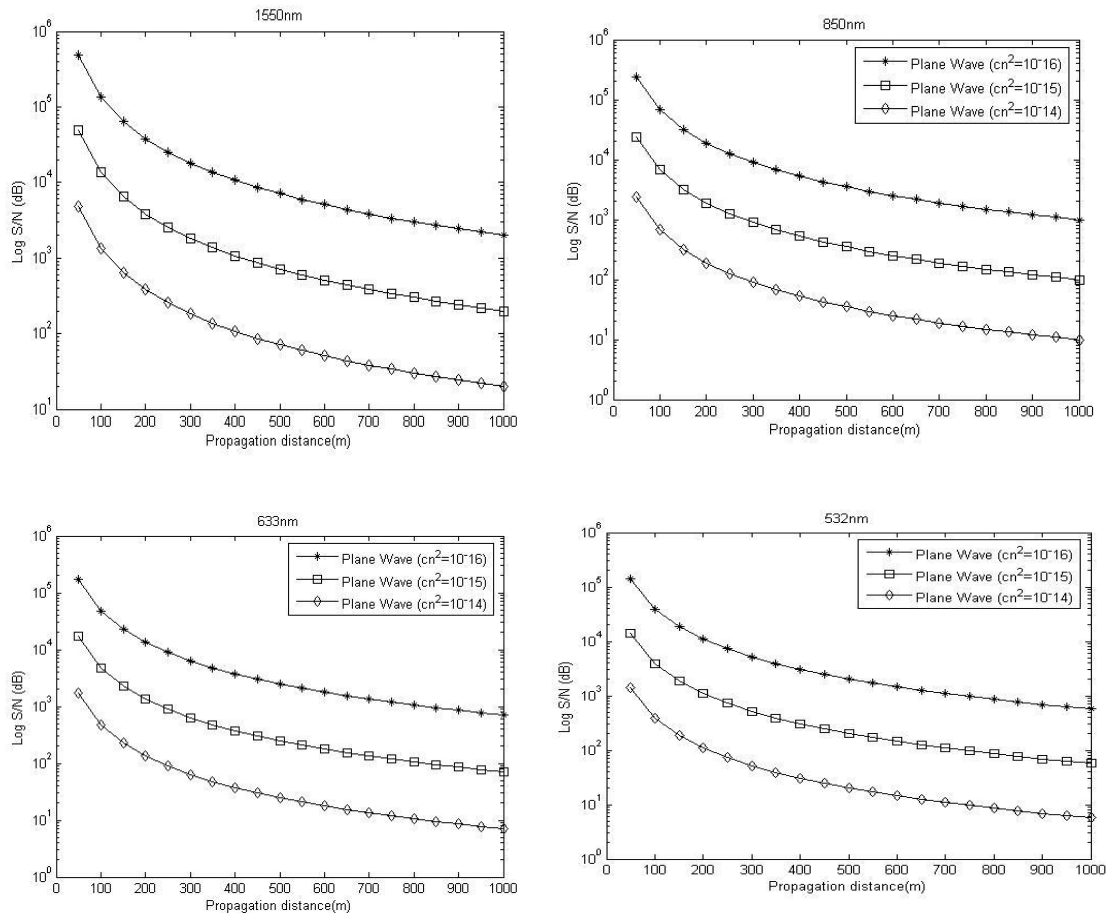


Fig. (10) The SNR versus the propagation distance for different values of c_n^2 to plane wave.

When the turbulence is not weak ($C_n^2 \geq 10^{-14} m^{-2/3}$), the S/N calculated depends on tailor for different values of α (the strength of turbulence). Therefore we studied S/N for (ϵ) is very small with the approximation using tailor series as shown in fig. (11), we observe that the close behavior and the resulting values of S/N for different values of (α) compare with ϵ very small (not weak).

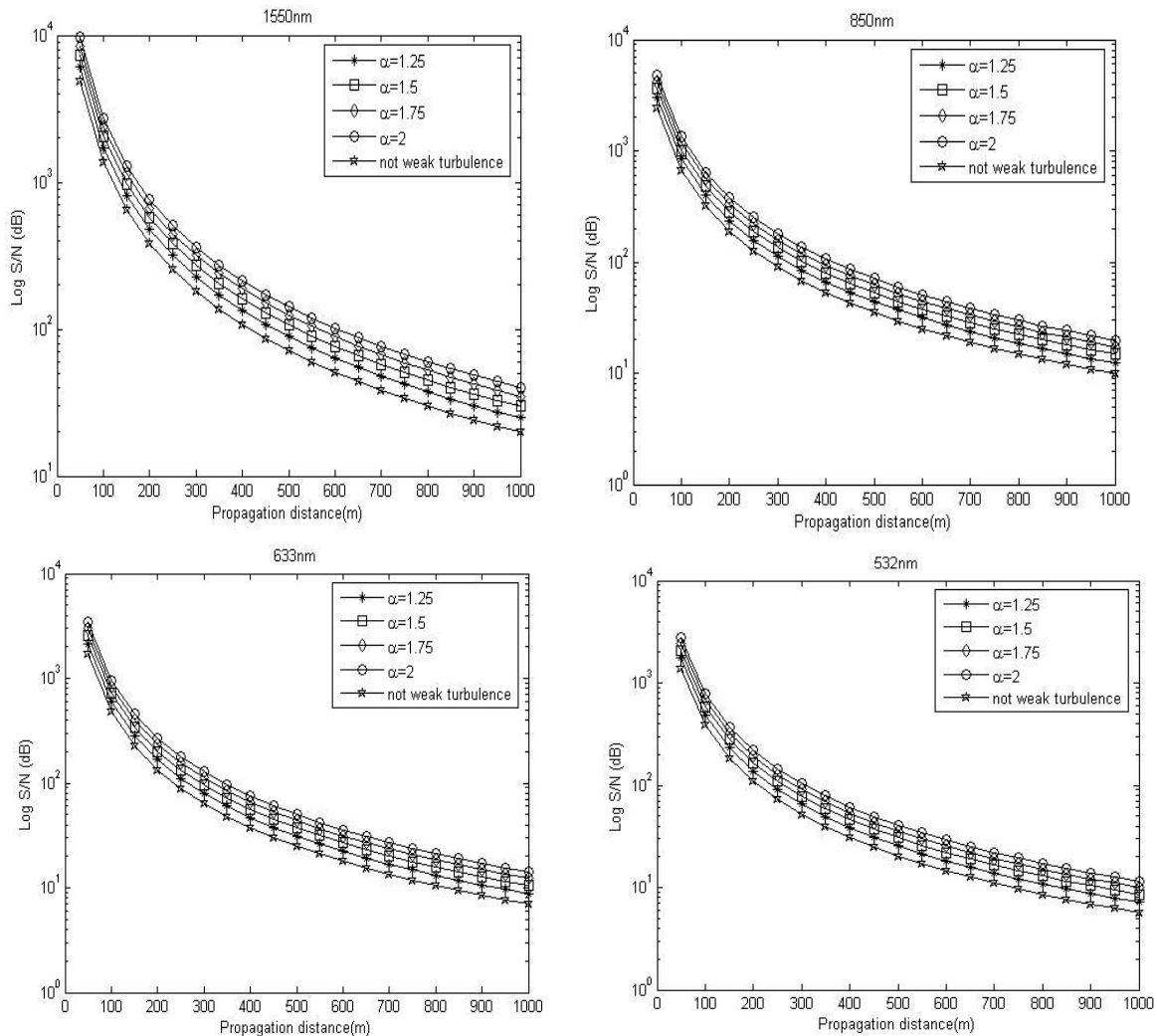


Fig. (11) The SNR versus propagation distance for different values of α at ($C_n^2 = 10^{-14} m^{-2/3}$)

It is well known the optical beam in the turbulence atmospheric transmission medium using 1550nm wavelength is less attenuation (large S/N) compare with the other wavelengths. For visible wavelengths (633, 532) nm we observe that these curves have the same behavior and very close.

V. Conclusions

It is well known that the optical beam affected by turbulence atmospheric by the temperature difference earth's surface and the atmosphere. The spherical wave was less Rytov variance than plane wave, especially the wavelength 1550 nm which was less Rytov variance than the wavelengths (850, 633, 532) nm at different atmospheric turbulence (10^{-16} , 10^{-15} , 10^{-14}) $m^{-2/3}$, on the other hand the scintillation by Rytov approximation was less for the wavelength 1550 nm from the applied wavelengths at the same conditions. The S/N for plane wave 1550nm is the better from the other wavelengths, where the visible wavelengths have very close behavior. The S/N at not weak turbulence compare with α (the strength of turbulence) studying, the best S/N at not weak turbulence compare with the strength of turbulence) at different values of α (1.25, 1.5, 1.75, 2), finally the best S/N at 1550 nm compare with the other wavelengths.

VI. References

- [1] O. Bouchet, H. Sizun, C. Boisrobert, F. De Fornel, P. N. Favennec, "Free-Space Optics: Propagation and Communication", Library of Congress, by ISTE Ltd, 2006.

- [2] N. Blaustein, S. Aron, A. Zilberman, N. Kopeika, " Applied Aspects of Optical Communication and Lidar", Taylor and Francis Group, 2010.
- [3] V. A. Kovalev, W. E. Eichinger, Elastic Lidar: Theory, Practice and Analysis Methods, John Wiley & Sons, Hoboken, NJ, 2004.
- [4] L. C. Andrews, R. L. Philips, "Laser Beam Propagation through Random Media", SPIE – The International Society for Optical Engineering, 1998.
- [5] L. C. Andrews, R. L. Philips and C. Y. Hopen, "Laser Beam Scintillation with Application", the International Society for Optical Engineering (SPIE), Bellingham, WA, 2001.
- [6] L. C. Andrews, "Field Guide to Atmospheric Optics", The International Society for Optical Engineering (SPIE), Bellingham, 2004.
- [7] M. AL- Naboulsi, H. Sizun, F. de Fornel, "Propagation of optical and infrared waves in the atmosphere", in proc. of the XXVIII th URSI general assembly, New Dalhi, 2005.
- [8] X. Zhu, M. J. Khan, " Free Space Optical Communication through Atmospheric Turbulence Channels", IEEE Transactions on communications,.Vol. 50, No. 8, 2002.
- [9] X. Guoliang, Z. Xuping, W. Junwei, and F. Xiaoyong, "influence of atmospheric turbulence on FSO link performance", Proc. SPIE Optical Transmission, Switching and Subsystems, Vol. 5281, 2004