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Extinction Coefficient For Fog Attenuation Via Non-linear Medium

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Abstract: Due to various inherent advantages, the FSO (Free Space Optics) is a dominant competitor for last mile connectivity in recent years. FSO systems transmit data in the form of light therefore major challenge in the implementation of these systems is weather effects on optical signals. The fog is one of the major cause of attenuation in FSO and several studies have been completed on fog. Various fog attenuation models based on theoretical and empirical approach were designed and proposed to convert visibility statistics into fog attenuation factor. In last decade several researchers attempted to compare these models with practical FSO link but no one has achieved accurate results because thesemodels were designed on the basis of theoretical assumptions only. These assumptions are based on three ideas that the fog particles are homogenous, that the transmission medium is homogeneous and that the linearity exists in transmission medium. In this research, all key assumptions of Mie theory were critically reviewed. Only idea of linearmedium has been considered and assumed as a non-linear medium for this research. Though two other assumptions of Mie theory remain unchanged. In this paper, the calculation of extinction coefficient for non-linear nature of the medium with homogeneous particles and homogeneous medium, merely considered for the simulation and results were compared with existing Mie theory assumptions.

Keywords: Fog models, extinction coefficient, Free space optics

1. INTRODUCTION

Currently the number of mobile users has been increased rapidly and many new mobile services introduced day by day, which results congestions at last mile connectivity. Both traditional last mile solutions such as radiofrequency (RF) and fiber optic cable have some limitations. RF connectivity at the last mile is not able to carry huge data form one node to other node and fiber optic cable is not easy to install and maintain. The alternate and predominant solution is free space optics (FSO) links which were designed to remove the limitations of both existing last mile solutions.

FSO provides the full duplex and protocols independent transmission of data. It workin Line of Sight (LOS) mode between two fixed points and support communication up to few kilometers in the form of optical signals. Due to optical signal data is transmitted through LASER (which travel from the air without any electromagnetic interference) and received by photo diode. Furthermore, the data is transmitted by using infrared signal (760 to 1550 nm) which gives two more advantages that include no need of any license from any regulation authority and provides compatibility with existing fiber optic cable entities. Like all other open air LOS links, FSO links are also weather dependent and at worst weather conditions these links become unavailable for a time. The major and dominant cause for unavailability of FSO links is fog,because fog particles radius and the operating wavelength of FSO link having comparable size. The volume of fog particles measured in terms of visibility for air traffic control (ATC) since air planes were used for transport. Several fog models were designed to convert the visibility statistics into optical attenuation factor suchas (Kruse *et al.* 1962), (Kim et al. 2001), (AlNaboulsi *et al.* 2004), (Ferdinandov et al.2009) and (Grabner *et al.* 2011).

In this decade, researchers are trying to compare these fog models with practical FSO links by using empirical approach but no one get exact results to validate these fog models. The work of (Ijaz *et al*. 2013b), validates the Kim model in under controlled laboratory (UCL) conditions. In our perivious work (Shah et.al 2015), we presents the comparision of these fog models with continental and dense maritime fog model, we provide an important conclusion that existing fog model were designed on the basis of Mie theory, which were designed on theoretical assumption. These assumptions includes homogeneous and linear medium with isotropic scatters (fog particles) but practically these assumptions are unsatisfied due to that existing fog models are not validate for practical FSO link. Furthermore, in this paper extinction coefficient due to fog is presented for non-linear medium with homogeneous and isotropic scatters.

This paper is organized in 5 sections, section one is about introduction of scattering of Fog particals,

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second section presents related work of field. Section Three provides materials and methods of approximation methods. Section four contains simulation results and discussion. Last section conclude the work. Followed by references.

2. RELATED WORK

Scattering problems involve two fundamental parameters complex refractive index $m = 1.33$ and dimensionless parameter x which is a ratio of radius of spherical particle $r = 0.01$ to 50 micron to the operating wavelength $\lambda = 680$ to 1550 ηm but the common operating wavelengths for FSO links are 680,750,780,850,1060 and 1550 η m. At the wavelength of 1550 η m effects of fog particles is minimum due to non-comparable size of operating wavelength as compared to size of fog particles. For FSO links the values of x varies from 0.1621 to 202.6834.Whenever the assumption considered that the particles are spherical in shape its true for small particles such as fog, mist, cloud and light rain as much as the size of the particles increases the shape of the particles becomes spheroid and oblate spheroid. The consideration of the assumption that the particles are spherical gives advantages over non-spherical particles. First advantage is that the geometry of circle is easy and other is these particles scatter the light or electromagnetic energy in isotropic manner.

Basically the solution procedure for calculating the aerosol scattering is the solution of Maxwell equations with proper boundary conditions but this one is very complex calculation method so there are many other short methods are available which gives the exact solution without using the Maxwell equation. Common types of approximation debated in different text books of scattering theory such as (Bohren and Huffman 2008), (Hulst and Van De Hulst 1957), (Van De Hulst 1980), (Van de Hulst 2012), (Deirmendjian 1994) are summarized in the table.1. As shown form the table description only Mie theory and VDH approximation is best situated for the calculation of scattering efficiency because the shape of the fog particles are spherical.

Table 1 : Common approximation types for Electromagnetic scattering.

#	Approximation	Condition
1	Rayleigh	$x << 1$ for m is arbitrary and $mx << 1$ for $\|m\|$ is large
2	Rayleigh-Gans	$\|m-1\|$ and $2x\|m-1\|$ must be small
3	Van De Hulsts	$\|m\| \to 1$
4	Ray Trace	$x \to \infty$
5	Mie Theory	$x =$ no limit and $m =$ no limit

3. MATERIAL AND METHODS

For the calculation of scattering efficiency the direct solution is the solution of Maxwell's equations with proper boundary condition, which is lengthy and complex calculation. Instead, of this method we can find the scattering efficiency by indirect method (approximation method) which summarized in Table:1. For the scattering efficiency from fog particles only Mie theory and VDH approximation are best situated for finding scattering efficiency due to constatnt refractive index, spherical shape of fog particles and ratio between operating wavelength of FSO link and radius of fog particles.

Mie Theory

In 1908 Gustav Mie gave glorious Mie theory which is exact solution of Maxwell equation with proper boundary conditions which describe the scattering and absorption of electromagnetic radiation by spherical and homogeneous particles. Mie theory gives scattering, absorption and extinction coefficient form two parameters the refractive index of ambient medium and size parameter. Size parameter is a function of radius of fog particle and operation wavelength of FSO link. Complex refractive index is a function of chemical composition of fog particles.

The main parameters for Mie calculation are amplitude of scattered field a_n and b_n which describes as follows

$$a_n = \frac{\mu m^2 j_n(mx)[x j_n(x)]' - \mu_1 j_n(x)[mx j_n(mx)]'}{\mu m^2 j_n(mx)\left[x h_n^{(1)}(x)\right]' - \mu_1 h_n^{(1)}(x)[mx j_n(mx)]'}$$

$$b_n = \frac{\mu_1 j_n(mx)[x j_n(x)]' - \mu j_n(x)[mx j_n(mx)]'}{\mu_1 j_n(mx)\left[x h_n^{(1)}(x)\right]' - \mu h_n^{(1)}(x)[mx j_n(mx)]'}$$

where prime sign shows the derivative with respect to the argument; similar expressions exist for the coefficients c_n and d_n of the internal field.

$$c_n = \frac{\mu_1 j_n(x)\left[x h_n^{(1)}(x)\right]' - \mu h_n^{(1)}(x)[x j_n(x)]'}{\mu_1 j_n(x)\left[x h_n^{(1)}(x)\right]' - \mu h_n^{(1)}(x)[mx j_n(mx)]'}$$

$$d_n = \frac{\mu_1 m j_n(x)\left[x h_n^{(1)}(x)\right]' - \mu m h_n^{(1)}(x)[x j_n(x)]'}{\mu_1 m^2 j_n(mx)\left[x h_n^{(1)}(x)\right]' - \mu h_n^{(1)}(x)[mx j_n(mx)]'}$$

For the coefficients a_n, b_n, c_n and d_n the subscript n run form 1(The Index n runs from 1 to ∞, and Mie series become unending so to avoid the infinite series the values of n is trunked by using BH condition which is

$$n_{max} = x + 4x^{1/3} + 2$$

$$x = ka$$

$$a = \text{radius of sphare}$$

$$k = \frac{2\pi}{\lambda}, k(\text{wave number}), \lambda \text{ wavelength}$$

The scattering efficiencies of Mie scattering theory can be defined as

$$Q_{sca} = \frac{2}{x^2}\sum_{n=1}^{n_{max}}(2n+1)(|a_n|^2 + |b_n|^2)$$

These scattering efficiencies can be calculated only when the refractive index of the medium is a real number if the refractive index is a complex number then extinction efficiencies can be defined by the following series

$$Q_{ext} = \frac{2}{x^2}\sum_{n=1}^{n_{max}}(2n+1)Re(a_n + b_n)$$

The absorption efficiencies is obtained by taking the imaginary part of the complex refractive index or simply subtraction of scattering efficiencies form extinction efficiencies which gives as

$$Q_{abs} = Q_{ext} - Q_{sca}$$

Sometimes the word cross section is also used instead of efficiencies. These cross sections or efficiencies can be normalized by dividing these terms with πr^2 and gives as follows

$$Q_{sca}^{norm} = \frac{Q_{sca}}{\pi r^2}$$

$$Q_{abs}^{norm} = \frac{Q_{abs}}{\pi r^2}$$

$$Q_{ext}^{norm} = \frac{Q_{ext}}{\pi r^2}$$

In FSO link case aerosol absorption is zero so aerosol scattering and extinction efficiencies are equal.

Vdh Approximation

In (Hulst and Van De Hulst1957), (Van De Hulst1980), (Van de Hulst2012) gives a good approximation of Mie theory by considering the non-absorbing spheres and defineQext in terms of a normalized parameter known as Van De Hulst's normalized parameter and denoted by ρ . He actually limit the case of Mie Theory which shows the generalfeatures of electromagnetic scattering by taking a condition of curve

$$\frac{1}{x^2}S(0) = k(i\rho)$$

For the values of m is only real part close to 1 and also up to 2 . He defined the condition for the value of m is as $|m-1| \ll 1$.The value of Van de Hulst's normalized parameter is given as

$$\rho = 2x(m-1)$$

Where x is the product of fog particle radius r with wave number k and n is the realpart of complex refractive index. The extinction efficiency is the function of VDH normalized parameter ρ and rewrite in trigonometric formis given as

$$Q_{ext}(\rho) = 2 - \frac{4}{\rho}\sin\rho + \frac{4}{\rho^2}(1-\cos\rho)$$

4. SIMULATION RESULTS AND DISCUSSION

The **(Fig:1, Fig:2 and Fig:3)** shows the Mie and VDH extinction efficiencies at 550 nm, 850 nm and 1550 nm respectively . As shown form the Fig:1 for 550 nm which is the maximum spectrum of sun light that Mie gives first maxima at 3.9 and VDH gives at 3.15. It is also noted from the Fig:2 that Mie gives first maxima at 3.4 and VDH gives at 3.9 on the 850 operating wavelength and from the Fig:3 Mie gives first maxima at 3.9 and VDH gives at 3.2 on the 1550 nm operating wavelength When both extinction efficiencies are plotted on same plot it is clear that all maxima and minima occur at the same values of x for Mie and 0.66xfor VDH as shown in Fig:3 this point is same when the operating wavelength 550 nm and 850 nm.Furthermore, it is also noticeable that at 1550 nm VDH gives minimum attenuation therefor this wavelength is suitable choice for FSO links.

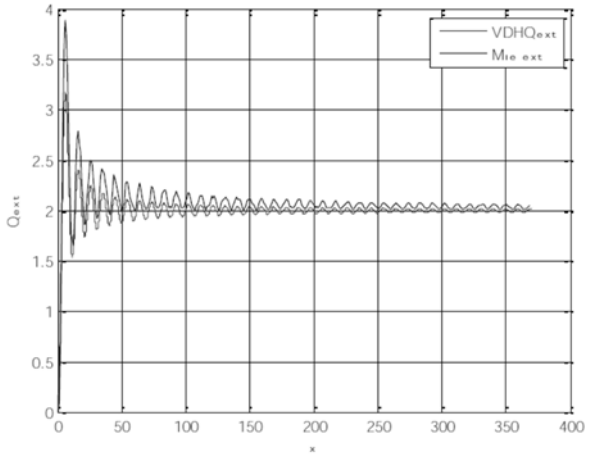


Fig.1 :Extinction efficiency at 550nm

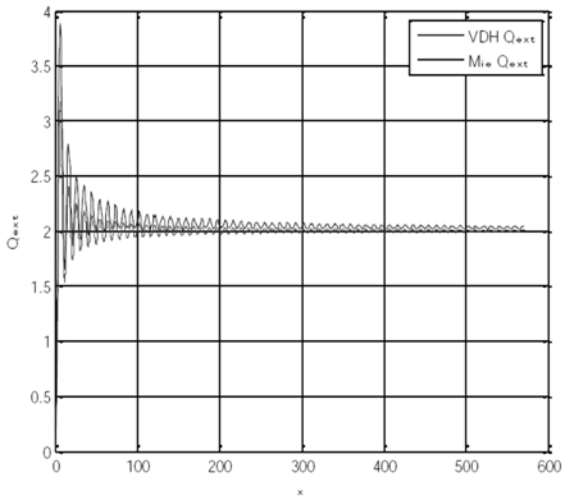


Fig.1 : Extinction efficiency at 850nm

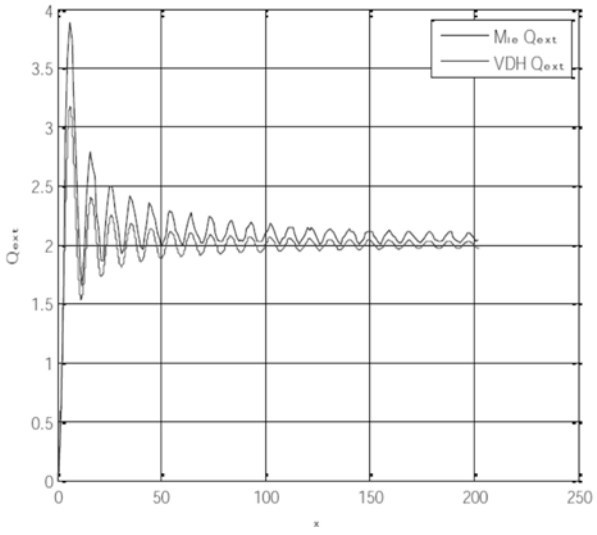


Fig.3 : Extinction efficiency at 1550nm

5. CONCLUSION

All the theoretical fog models are based on visibility statistics and designed by calculating the volume scattering using rigorous Mie theory by the assumption of homogenous and linear medium with isotropic scatters. The identical results of Kim and UCL condition motivate that theoretical models can give almost identical results in outdoor atmosphere when they will be designed with the assumption of heterogeneous and non-linear medium associated with non-isotropic scatters. The extension form of scattering efficiency from linear to non-linear nature was achieved by using VDH approximation. In conclusion, the fog models will design by using VDH approximation, which gives an improved result as compared to existing fog models in outdoor atmosphere**.**

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