# All-optical Fog Sensor for Determining the Fog Visibility Range in Optical Wireless Communication Links

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**Abstract:** The goal of this research work is to use an all optical based fog sensor to study the atmospheric visibility of fog and its constituents on the optical wireless communication (OWC) links in a controlled laboratory test-bid. The fog sensor measures the transmittance of the Infrared (IR) radiations which is used to determine the link visibility. Experimental results obtained show that using the fog sensor the visibility range from 0.37 – 1 km and above with respect to different fog density can be predicted.

## 1. Introduction

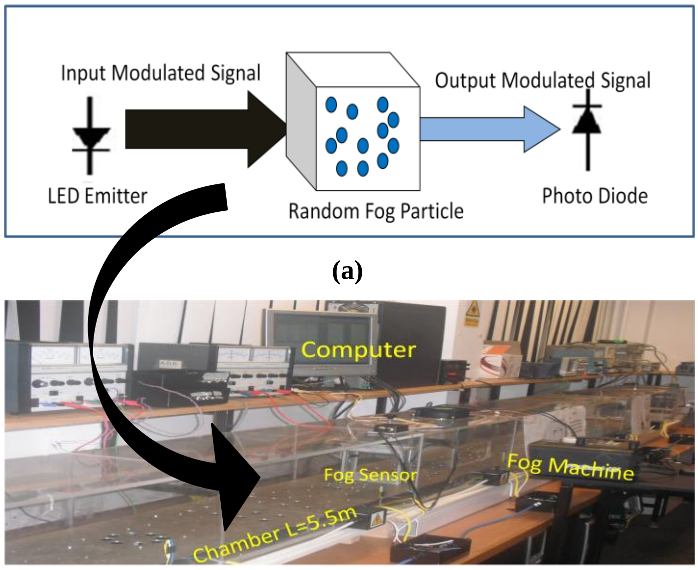
As the number of users using applications requiring a large bandwidth is increasingly growing, the bandwidth limits of current wireless systems in particular radio frequency based technologies (in particular 60 GHz band) are being stretched. Recently, OWC systems with a huge unlicensed bandwidth capability have attracted a great deal of interest from a number of sources including academia, industry, and standardization bodies. This huge bandwidth represents high potentials in terms of capacity and flexibility, thus making OWC technology particularly attractive candidate for multi-gigabit wireless applications (including uncompressed video, audio streaming and multi-gigabit file transferring) offering better quality and user experience, in areas to complement radio frequency based services [1-3].

Despite unique capability of OWC systems such as higher transmission capacity, security, low deployment cost, and immunity to the electromagnetic interference compared to existing communications systems, there are a number of technical challenges that needs addressing. In OWC or also known as free-space optical communications (FSO) for outdoor applications, the optical beam propagation through the atmosphere experiences attenuation and signal power level fluctuation [2 - 4]. Attenuation of optical intensity mainly caused by the absorption, scattering and refraction of optical waves by gas molecules, snow, rain and fog. For link lengths exceeding several hundred meters fluctuations of received optical signal present a severe problem. Fog has the largest impact on FSO links. Under heavy fog conditions the link range is limited to a few hundred meters [5].

The meteorological definition of fog is when the link visibility is less than 1 km [4, 6]. The visibility is the prime parameter for investigating the affects of fog on outdoor FSO systems. The system performance, the link length and the availability of the FSO systems can be optimized by investigating the visibility. One of the major issues in FSO systems operational at different sites is the lack of system design parameters such as the attenuation due to fog which is function of visibility. The visibility data is not available for all the sites. This could be due to the high implementation cost of transmissometer to measure visibility. In this paper we introduced a laboratory optical fog sensor which has been designed to characterise the link visibility for different fog channel conditions.

## 2. Design of the Fog Sensor

The density of the fog, which is function of the visibility, can be measured within a controlled environment, as outlined in Fig. 1. A portable optical fog sensor composed of an IR LED at a wavelength of 880 nm, a photo-detector with a peak response at 880 nm, and an optical band pass filter to block all background radiations is positioned at the centre of the atmospheric chamber, see Figs. 1(a) &(b). The optical source and photo-detector separated apart by 13 cm are heated up to the room temperature using a heating wire mounted around them. This is to ensure that no water droplets will form, thus no further losses due to absorption and refraction of IR light beam. The volume of atmospheric chamber is 5.5×0.3×0.3 $m^3$. A modulated laser beam generated at one end is collected at the other end via a photo-detector followed by a trans-impedance amplifier. Characterisation of visibility depends on the fog density within the chamber. A fog generator is used to fill the chamber with a controlled amount of fog from low to thick fog.




**(a)**

**(b)**

**Figure** 1**. (a) Optical fog sensor, and (b) atmospheric chamber.**

The fog sensor is controlled by a computer where 1 kHz digital signal generated by a sound card is used to drive the IR transmitter, see Fig. 2. The received signal is processed using the same sound card and the data is analysed both in time and frequency domains using Matlab.

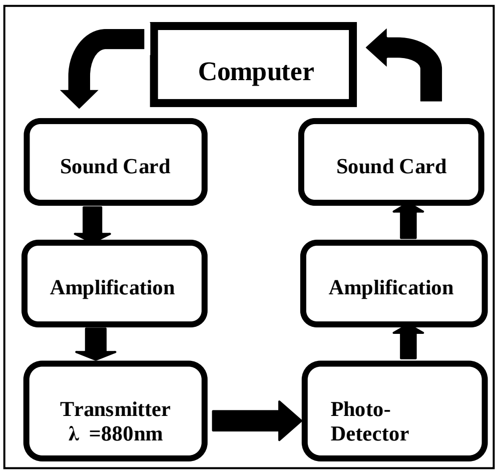



**Figure 2. Block diagram of fog sensor.**

## 3. Fog Sensor and Visibility

The data captured by the fog sensor is converted to the link visibility using the empirical model based on the contrast threshold. In 1924, Koschmieder defined the visibility as the distance to an object at which the visual contrast of an object drops to 2% of the original visual contrast. The 2% drop in the visual contrast is known as the visual threshold $T_{th}$ over the atmospheric propagation path [4, 6]. The meteorological visibility $V$ can be expressed in atmospheric attenuation coefficient $\gamma$ using the visual threshold $T_{th}$ [8] as:

$$V(\text{km}) = \frac{10\log_{10}(T_{th})}{\gamma} \qquad (1)$$

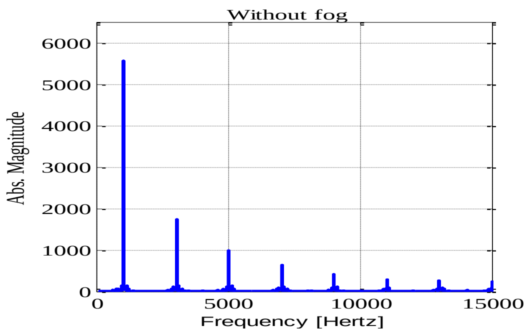
The attenuation coefficient $\gamma$ can be calculated from the Beer-Lambert law given by [6 - 8]:

$$T(f) = \frac{I(f)}{I(0)} = \exp(-\gamma z) \qquad (2)$$

*I*(*f*) and *I*(0) are the intensity of the optical signal with and without fog, respectively. The attenuation coefficient is measured for different density of fog from low to dense using (2), which in turn is applied to (1) to obtain the link visibility. Note that the fog sensor output was normalized to "1" and "0" without fog and with a dense fog, respectively. The value of fog sensor is calibrated between "1" and "0" depending on the fog density within the chamber.

## 4. Results

The amount of fog introduced to the chamber will directly affect to the channel visibility and the transmittance measured at the fog sensor. The received signals in frequency domain with and without fog are shown in Fig. 3. The absolute magnitude level of the received signal without fog is 5500 which is equal to 1 V, whereas with fog, the level is 2900 equal to 0.5304 V. The visibility exceeds 1 km link range when the fog sensor value is close to "1", i.e. no fog is introduced (see Fig. 4). The experimental results obtained for visibility are categorized into two different regions according to the meteorological classification of atmospheric visibility [3, 6]. Note that for the visibility in the range of 0.5 – 1 km and 0.25 – 0.5 km are defined as the light fog and moderate fog respectively [6].

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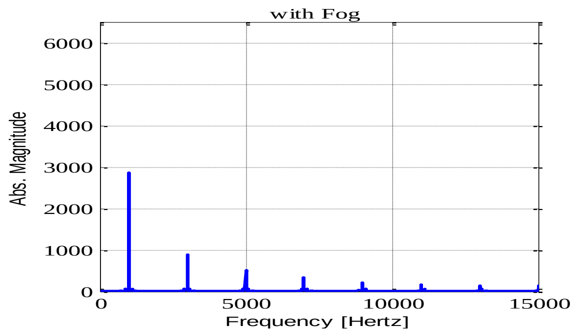



**(b)**

**Figure 3. The frequency spectrum of the received signal (a) without fog, and (b) with fog. The absolute magnitude level of received signal without fog is equal to 1 V.**

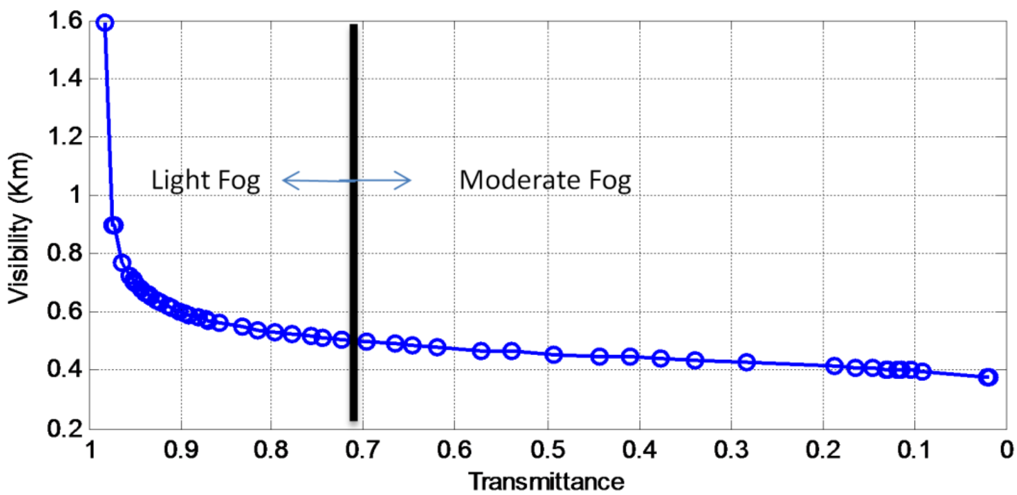
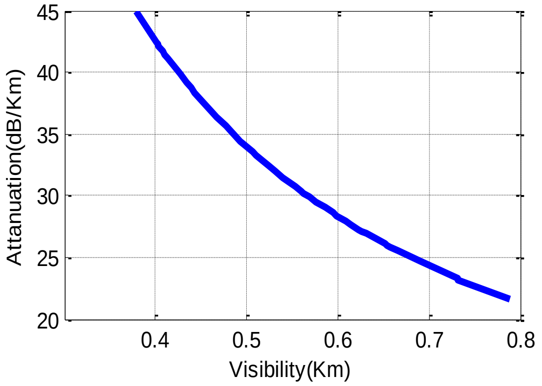



**Figure 4. The transmittance (*T*) of the fog sensor versus the visibility in km from light to moderate fog.**

Experimental value of the visibility derived from the fog sensor is plotted against the attenuation coefficient as shown in Fig. 5(a). The attenuation exceeds 45 dB/km as the visibility drops below 400m, for moderate fog case. This is inline with the attenuation data reported in [4, 8] for the visibility range less than 500 m. The attenuation against the transmittance of the fog sensor is depicted in Fig.

5(b). As the density of the fog increases the transmittance is decreases, thus resulting in increased attenuation, for example 45 dB/km at the transmittance of < 0.2.

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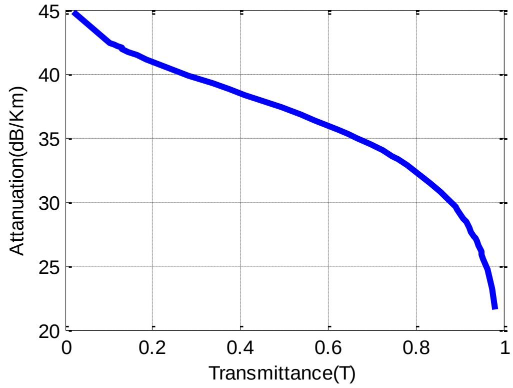


**(b)**

**Figure 5. (a) Experimental visibility versus attenuation (dB/km) and (b) transmittance of the optical fog sensor versus the attenuation coefficient (dB/km).**

## 7. Conclusions

In this paper we have shown the application of an all optical fog sensor in the FSO system for measuring optical attenuation due to light-to-moderate fog in a laboratory based atmospheric chamber. Using the Koschmieder law, the fog sensor is used to determine the visibility (and attenuation) in the range of 0.37 – 1 km and above. Work to develop the fog density measurement tool for all ranges of visibility is in progress and the results will be published in due course.


## Acknowledgments

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## References


[1] P. Mandl, P. Schrotter, and E. Leitgeb, "Wireless synchronous broadband last mile access solutions for multimedia applications in license free frequency spectrums," 6th International Symposium on Communication Systems, Networks and Digital Signal Processing, pp. 110 -113, 2008.

[2] A. K. Majumdar, and J. C. Ricklin, Free-Space Laser Communications, Principles and Advantages, Springer Science, LLC, 233 Spring Street, New York, NY 10013, USA, 2008.

[3] O. Bouchet, H. Sizun, C. Boisrobert, F. de Fornel, and P. Favennec, Free-space optics, propagation and communication, ISTE, pp.87 - 127, 2006.

[4] I. I. Kim, B. McArthur, and E. Korevaar, "Comparison of laser beam propagation at 785 nm and 1550 nm in fog and haze for optical wireless communications", Proc. of SPIE, 4214(issue??), pp. 26 - 37, 2001.

[5] H. Willebrand, and B. S. Ghuman, "Free space optics: enabling optical connectivity in today's Network", Indianapolis, IN: SAMS publishing, 2002.

[6] M. S. Awan, L. C-Horvath, S. S. Muhammad, E. Leitgeb, F. Nadeem, and M. S. Khan, "Characterization of fog and snow attenuations for free-space optical propagation", J. of Communications, 4(8), pp. 53 - 545, 2009.

[7] M. A Naboulsi, F. de Fornel, H. Sizun, M. Gebhart, E. Leitgeb, S. S. Muhammad, B. Flecker, and C. Chlestil, "Measured and predicted light attenuation in dense coastal upslope fog at 650, 850, and 950 nm for free-space optics applications", Proc. of SPIE, Optical Engineering, 47(3), pp. 036001.1 - 036001.14, 2008.

[8] A. Prokes, "Atmospheric effects on availability of free space optics systems", J. of Optical Engineering, 48(6), pp. 066001-10, 2009.