An Empirical Expression for Attenuation Coefficient Evaluation of FSO Links During Night-Time Over Maritime Area of Piraeus Port in Greece

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Abstract—Free space optical (FSO) systems are extensively used in modern communication networks, due to the high performance and security they can achieve. However, their performance is strongly affected by the weather conditions and the various atmospheric phenomena. In this work, the influence of the atmospheric condition on an FSO system installed in maritime environment is experimentally investigated. More precisely, an empirical experimental model for the attenuation coefficient/optical power received based on the impact of main atmospheric parameters, i.e. relative humidity, temperature, etc, will be extracted for an FSO system in the maritime environment of the port of Piraeus, during night-time. This model will be validated comparing the measured attenuation coefficient/optical power received to the one that is estimated from the experimental model. The existence of such a model will be a very useful and important tool in the deployment of modern FSO communication networks, as the expected performance of the system will be estimated with high precision through basic atmospheric parameters of the area which can be easily estimated.

Keywords – Free Space Optical Communications; Signal propagation; Atmospheric Losses

1. Introduction
During the last two decades, FSO systems have attracted intense interest in the field of wireless communications, due to the advantages they offer that make them a trustworthy solution in high demanding modern networks of the next generation, i.e. 5G/5G+. Their main advantages are the low operational and installation cost and the very high data rate they can achieve. On the other hand, the FSOs systems’ performance strongly depends on the weather and atmospheric conditions of the atmospheric channel that are impossible to be precisely predicted. The main factor that attenuates the power of the transmitted signal is the atmospheric absorption while the atmospheric turbulence is another very important factor that degrades the beam’s power. In order to investigate how these factors affect the performance of these systems, various theoretical models that describe turbulence and absorption have been developed, [1]-[7]. In order to verify the validity of such models, many experimental links have been deployed around the world investigating the performance and the availability of FSO systems under various weather and atmospheric conditions, [8]-[18]. Furthermore, experimental results are used not only for theoretical model validation but empirical models estimating accurately many performance parameters can be extracted. Such models have a great impact before deploying a new FSO system, as knowing the weather and atmospheric conditions of the area, the performance of the system can be estimated with higher accuracy than a theoretical model can provide. In this work, a horizontal terrestrial FSO link has been installed over the sea in the maritime environment of Piraeus Port in Greece in order to extract an empirical model for the experimental estimation of the influence of the attenuation as a function of the atmospheric parameters such as the relative humidity, the wind speed and the air temperature.

The remainder of this work is organized as follows: In section 2, the experimental setup is analyzed, in section 3, the theoretical background is presented, while, in section 4, the empirical model is constructed. Finally, the numerical results and the corresponding conclusions are shown in sections 5 and 6, respectively.

2. Experimental Set up
The experimental FSO link under consideration consists of two FSO transceivers. The one of them is installed at the roof of a building of the Hellenic Naval Academy at the entrance of Piraeus port while, the other one, is located at the beacon of Psyttaleia island. The optical wireless link is along a horizontal path 30 meters above the sea. The geographical layout where the FSO is installed appears in Fig 1.
According to Beer Lambert law, the optical power, \( P_r \), at the receiving end’s photodiode, drives an electronic circuit that gives a voltage signal at its output that is proportional to the optical power of the signal, \( P_t \), [19]. This output voltage is referred as receiver signal \( U_0 \) and can be estimated as, [10],[12],[19]:

\[
U_0 = \frac{1}{L} \ln \left( \frac{P_r}{RSSI} \right)
\]  

(2)

4. The Empirical Model for the Attenuation Evaluation

The main phenomena that affect the attenuation coefficient depend on the channel’s absorption and the atmospheric turbulence effect. Thus, the value of \( b \) can be estimated as,[2],[10],[12],[13]:

\[
b = b_a + b_t
\]  

(3)

with \( b_a \) being the attenuation coefficient which is proportional to the visibility and \( b_t \) represents the attenuation coefficient due to atmospheric turbulence and it can be estimated as, [14]:

\[
b_t = 2\sqrt{23.17C_n^2 k^{7/6} L^{1/6}}
\]  

(4)

where \( k \) stands for the wave number of the optical signal and \( C_n^2 \) is the refractive index structure parameter. The value of \( C_n^2 \) depends on the atmospheric and weather conditions and has been shown that it can be estimated using various theoretical or/and empirical and experimental models, [1],[10],[14].

In this work, the model of Sadot-Kopeika, [1], will be used and the refractive index structure parameter is given as, [1],[20],[21]:

\[
C_n^2 = 3.8 \cdot 10^{-14} W + 2 \cdot 10^{-15} T - 2.8 \cdot 10^{-13} RH + 2.9 \cdot 10^{-17} RH^2 - 1.1 \cdot 10^{-19} RH^3 - 2.5 \cdot 10^{-18} WS + 1.2 \cdot 10^{-15} WS^2 - 8.5 \cdot 10^{-17} WS^3 - 5.3 \cdot 10^{-13} m^{-2/3}
\]  

(5)

with \( W \) being the temporal hour weight, \( T \) stands for the temperature in Kelvin degrees, \( RH \) is the relative humidity and \( WS \) represents the wind speed in m/s. All these meteorological parameters are measured in real time conditions from the installed weather station.

Furthermore, absorption is another important factor that attenuates the power of the transmitted signal. This factor strongly depends on the parameter of relative humidity, \( RH \), [2],[8],[9], [11], [14], [15]. So the formula that can estimate the attenuation coefficient of the absorption as a function of relative humidity can be given in the form, [8],[9],[10],[15]:

\[
b_a = p_1 e^{-p_2 RH} + p_3
\]  

(6)

where \( p_1 \) is the scale parameter, \( p_2 \) is the decay parameter and \( p_3 \) is an appropriate fitting constant.

5. Experimental Results

The experiment was held between September to December of 2019, collecting measurements of RSSI and atmospheric parameters daily every 1 minute. The experimental results are taken for the time zones of [00:00 - 05:00] and [20:00 - 23:59]. The reason was to avoid the sunlight radiation in order to present an accurate enough, first experimental result. The weather is assumed to be mild so samples with wind speed higher than 6m/s and any kind of precipitations were rejected. Temperature and relative humidity has also limits due to Sadot-Kopeika turbulence model, [20],[21]. Thus, the limit values which have been taken into account are presented in Table 2.
The measurements of wind speed, temperature, relative humidity and RSSI for all the samples of the experiment, i.e. all the days which are taking part in the experiment, are presented in Fig. 2.

Then from (2), we calculate the experimental attenuation coefficient, $b$, and the results are presented in Figure (3).

Then, from (3)-(5), the empirical model for the attenuation coefficient is extracted, using the appropriate high order polynomial fitting tools. The values of the parameters of (5) that were estimated according to the best characteristics are presented in Table 3.

### Table 2: Limit parameter values for the experimental model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>282K - 305K</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>&lt;6m/s</td>
</tr>
<tr>
<td>Rain rate</td>
<td>0 mm/Hour</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>14%-92%</td>
</tr>
</tbody>
</table>

### Table 3: Parameter values for the experimental model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_1$</td>
<td>0.085</td>
</tr>
<tr>
<td>$p_2$</td>
<td>0.008</td>
</tr>
<tr>
<td>$p_3$</td>
<td>0.212</td>
</tr>
</tbody>
</table>

From Figs (4), (5) and (6), it can be seen that the empirical model can describe satisfactorily the experimental results. This accuracy can be verified through the RMSE, mean and standard deviation values of Table 4, that were calculated for the whole model and for three days of the experiment, which have been chosen at random.
6. Conclusions
In this work, an empirical model of the attenuation coefficient $b$ was extracted for maritime environments using an FSO link at the port of Piraeus, Greece. The model that was extracted presents satisfactory accuracy for very low RMSE values. Such model can be further improved in the future as many other parameters, such as the air pollution and the presence of dust in the atmosphere, that affect the atmospheric channel, can be added in order to achieve more accurate characteristics. Additionally, in the next step, the influence of solar radiations should be taken into account in order to improve the accuracy of the model for both day-time and night-time hours.

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REFERENCES