Commun.Fac.Sc.Univ.Ank.Series A2-A3
Volume 57, Number 1, Pages 21-30 (2015)
DOI: 10.1501/commua1-2_0000000085
ISSN 1303-6009

VISIBILITY BASED OPTICAL WIRELESS AVAILABILITY ASSESSMENT FOR CONTINENTAL CLIMATE CONDITIONS

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(Received: October 04, 2014; Accepted: June 10, 2015)

ABSTRACT

Potential application of the cumulative distribution function of the airport visibility data, a statistical technique suggested and tested for various regions in Europe, is verified for optical wireless availability and range assessment in the city of Ankara, the regional center of continental climate mid – Anatolia. Results, obtained by computations with reference to the system parameters of the enterprise class Ankara University optical wireless link have been presented.

KEYWORDS: Airport visibility data, Availability, Cumulative Distribution Function, Link range, Optical Wireless Communication

1 INTRODUCTION

Optical wireless communication, OWC, is identified to offer the well – known advantages over radio waves [1, 2], such as the transmission of higher bandwidth data rates for distances up to about 4 km. However, OWC links use the air as the transmission medium where the adverse weather conditions cause shorter *visibility* occurrences. Reduced visibility, on the other hand, means increased laser signal power loss. Consequently, historical *airport visibility data* can be utilized to assess the link *availability* and *range* by power loss evaluation.

A literature survey has indicated that the link availability assessment is possible by the statistical analysis of the airport recorded visibility values, alone [3]. The suggested statistical analysis is based on the *cumulative distribution function* (CDF) of the visibility and has yielded positive results in order to estimate the OWC availability for the mid-north and especially the Mediterranean regions of Europe.

The main objective of the present study is to verify the applicability of the CDF approach to the airport visibility data recorded in the mid-Anatolian city of Ankara, the Asian part of Turkey, where the typical continental climate prevails. In the computations, the technical parameters of the enterprise class Ankara University OWC system are considered [4, 5] to confirm the statistical model.

2 POWER LOSSES

As summarized in Figure 1, the laser power losses can be divided mainly into three different groups: (a) system loss, (b) geometric loss, and (c) atmospheric attenuation.

The *system* loss, loss(system) is the sum of *pointing* error, loss(pnt) and *optical* losses, loss(opt), and is constant for a given OW link. The optical loss is due to power decrease at the lenses and optical filters.

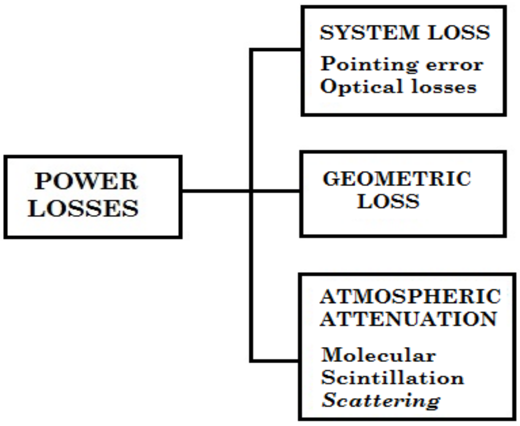

Figure 1 Schematic summary of power losses due to degrading factors in a general optical wireless link

The geometric loss, loss(geo), is a consequence of the laser beam spread and can be computed using Eq. (1), [6].

$$\text{loss}(\text{geo}) = S(\text{beam}) / S(\text{rec}) = 20\log\left(R\theta / D\right) \ (\text{dB}) \qquad (1)$$

where S(beam): beam cross-section area at range R (m^2), S(rec): receiver lens area (m^2), θ: beam divergence (mrad), D: receiver lens diameter (m).

Atmospheric effects: Molecular absorption is negligible, because the generally used laser wavelengths 785, 850 and 1550 nm coincide with the atmospheric transmission windows [7]. The effect of the scintillation due to turbulence is almost constant, for ranges up to 4 km [6]. The *scattering (Mie)* of the laser rays by fog droplets is therefore the dominant atmospheric effect and is quantified by the *attenuation coefficient,* σ, Eq. (2), [8].

$$\sigma = 3.91/V \left(\frac{\lambda}{550nm} \right)^{-q} \quad (km^{-1}) \qquad (2)$$

where V: visibility (km), λ laser wavelength (nm), q is the particle size distribution coefficient given in [8] and varies with V,

$$q = \begin{cases} 1,3 & \text{for } 6,0 < V < 50,0 \text{ km} \\ 0,16.V+0,34 & \text{for } 1,0 < V < 6,0 \text{ km} \\ V-0,5 & \text{for } 0,5 < V < 1,0 \text{ km} \\ 0 & \text{for } \quad V < 0,5 \text{ km} \end{cases}$$

Atmospheric *attenuation* in terms of dBloss/ km, Eq. (4), can be derived from Eq. (3) for R = 1 km [1 – 3].

$$P\ rec = P_0.e^{-\sigma R} \qquad (3)$$

where P(rec): power received at distance R, P_0:laser transmit power.

$$Attenuation\text{:dB/km} = 4,343\ .\sigma \qquad (4)$$

dBloss/km data, for λ=1550 nm laser wavelength, in Table 1 are computed sequentially from Eq. (2) and (4). The visibility limits corresponding to various weather conditions are adapted from International Visibility Code [9].

Table 1 Power Loss as a Function of Visibility

WEATHER CONDITIONS	VISIBILITY	dBloss/km (λ=1550 nm)
DENSE FOG	0 m	
	50 m	340,0
THICK FOG		
	200 m	84,9
MODERATE FOG		
	500 m	33,0
LIGHT FOG		
	770 m	17,9

	1,0 km	10,2
THIN FOG	1,9 km	4,6
HAZE	2,0 km	4,3
	2,8 km	2,7
LIGHT HAZE	4,0 km	1,5
	5,9 km	0,8
CLEAR	10,0 km	0,4

It is clear that the visibility data suffice to determine the value of σ and dBloss/km.

3 VISIBILITY DATA

The visibility data, recorded over three years, at Ankara Etimesgut airport [10] are based on the 2% transmission (17 dB) criterion for visibility with reference to METAR [11]. *Attenuation* is then expressed as in Eq. (5).

$$\text{Attenuation}= {}^{17}\!/_{V} \; \left({}^{\lambda}\!/_{550nm}\right)^{-q} \quad \text{(dB/km)} \qquad (5)$$

4 LM, AVAILABILITY

The *link margin*, LM, is the power remaining at a distance R, to counter the atmospheric attenuation, Eq. (6)

$$LM=[P_0 - P(sen) - loss(constant)] - loss(geo) \quad \text{(dB)} \qquad (6)$$

where P(sen):receiver detector sensitivity,
loss (constant) =loss(pnt)+loss(opt)+loss(scn)

Consequently, the link will be *available* provided that LM is greater than the atmospheric attenuation as indicated Eq. (7) which is arranged from Eq.(5) and (6).

$$V \geq \left(\frac{17.R}{LM}\right) \left({}^{\lambda}\!/_{550nm}\right)^{-q} \quad \text{(km)} \qquad (7)$$

From the preceding, the availability can be expressed as a function of the minimum required visibility, Vmin, as defined in Eq. (8).

$$
\begin{aligned}
\text{Availability}=\text{Probability}&\left[\text{LM} \geq \text{loss} \quad \text{atm} \quad\right] \\
&=\text{Probability}\left[V \geq \text{V}_{\min} \quad R \quad\right] \\
&=1-F\left[V_{\min} \quad R \quad\right]
\end{aligned} \tag{8}
$$

where F is the cumulative distribution function, CDF, obtained from the probability of airport visibility data, PDF, [3].

5 RESULTS

5.1 SYSTEM PARAMETERS

For all the computations, starting from LM, availability, then the range assessment, the parameters of an existing system, namely 2,9 km enterprise class Ankara University OWC link are used [4, 5] , Table 2.

Table 2 Ankara University OWC system parameters

Transmitter	
P_0	7 - 640 mW 9 - 28 dBm
λ,θ	1550 nm, 2,8 mrad
Receiver	
P(sen)	- 36 dBm (PIN)
D, lens	0,2 m
Losses	
loss(pnt)	3 dB
loss(opt)	3 dB
loss(scn)	5 dB
loss(constant)	11 dB

It should be noted that the transmitter laser power is adaptive from 9 dBm for clear to 28 dBm for unfavorable weather conditions, respectively.

From Eq. (6), LM=f(R) function is plotted in Fig. 2, for weather condition dependent limits of the variable transmit laser power, P_0. Figure 3 is the attenuation, in terms of dB/km as derived from the data of Figure 2. The combination of the Figure 3 data with that of Table 1 is the relationship between the visibility V and link range, R, Figure 4.

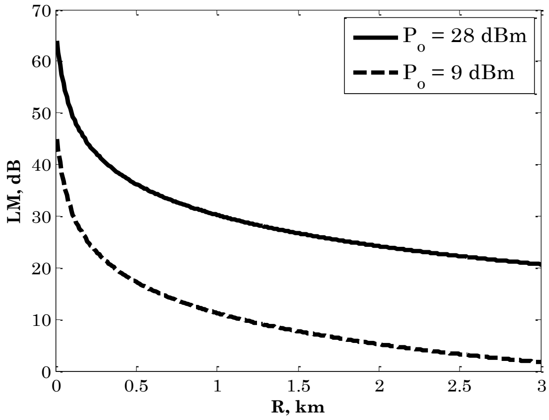

Figure 2 Variation of link margin with range for minimum and maximum laser transmit power: Eq. (6).

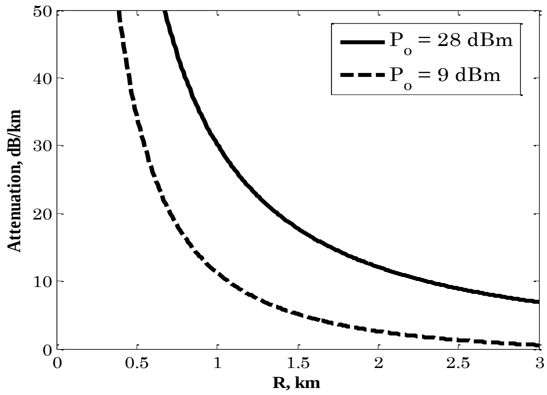

Figure 3 Variations of attenuation with link range

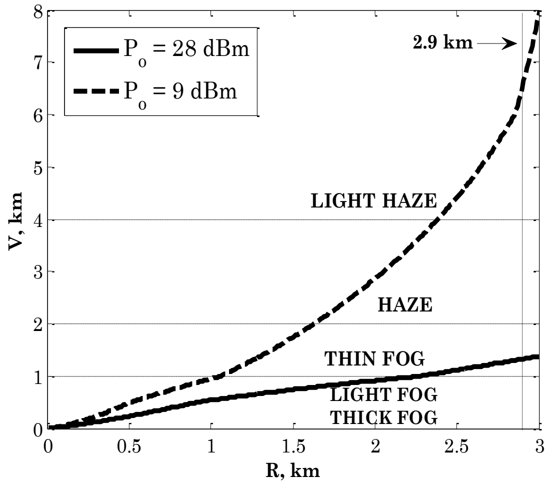

Figure 4 Variations of visibility with range for different weather conditions, from data of Figure 3 and Table 1

5.2 CUMULATIVE DISTRIBUTION FUNCTION

An initial analysis of the airport visibility data indicated that over the months from April to October inclusively, mostly summery, no link unavailability is expected. However, the remaining months, November to March, are critical from the point of high link cut – off likelihood.

CDF vs. visibility, Figure 5, is drawn through the following steps: (a) From the number of observations for each V, probability density function PDF data, (b) then added to give cumulative distribution function CDF data, (c) the resulting data are fitted approximately to a third – order polynomial [3], the solid line in Figure 5.

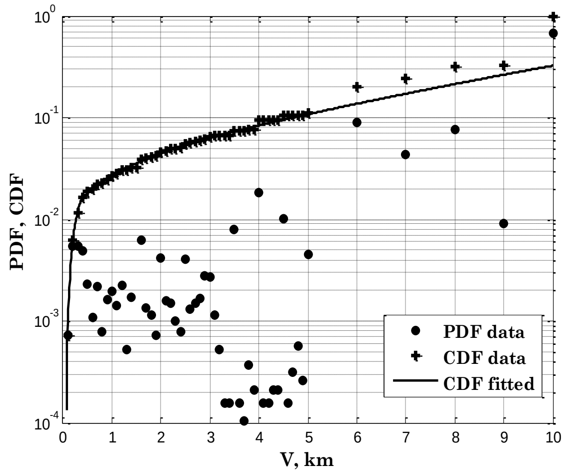

Figure 5 PDF, CDF and approximated CDF vs. visibility for critical months

Equation (8) is the basis for the availability computation, at that V is converted to R via Figure 4 data. Considering the regional critical months, November to March:151 days in total, and the Ankara University OWC system parameters, Figure 6 displays the variation of the availability with the link range.

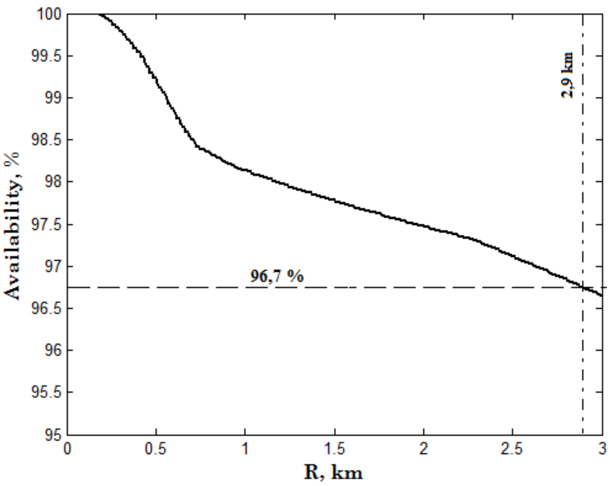

Figure 6 Variations of availability with range for the critical months

6 CONCLUSION

In this work, the initial elimination of the favourable months is based on the threshold criterion of visibility which is 6 km or greater, i.e. dBloss/km = 0,8, Table 1. For an OWC link of R=2,9 km, the total power loss is 2,3 dB or less, and is therefore negligible. Apart from shortening the airport visibility data treatment, the consideration of the unfavourable months alone, November to March, inclusively, means a more realistic availability assessment.

The CDF based Figure 6 indicates that for the range R=2,9 km, the *estimated* availability is 96,7% which corresponds to downtime of 4,98 days, taken over the critical months, 151 days. For the enterprise systems, on the other hand, the availability requirement is 99%, [9], the downtime is therefore 3,65 days which is approximately and practically equal to the estimated value, so as to confirm the possible application of the CDF approach to the geographical region of interest.

It has been decided, finally, that considering the positive findings reported in the literature for the Mediterranean region of Europe [3] and experimental evaluation of the Ankara University OW system [4, 5], the results of the present study, the CDF approach can be used in the construction of a countrywide optical wireless availability map for Turkey, similar to that published such as Brazil [12].

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