

Availability Assessment of Optical Wireless Links

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Abstract: - The paper deals with a statistical model of optical wireless links. The model is based on a combination of model of the atmospheric transmission channel at the installation site and the model of optical wireless link in ideal atmosphere. It allows an estimation of link availability based on the knowledge of the dependence of link margin on the transceiver distance for particular parameters of a link and the dependence of the exceedance probability on atmospheric attenuation at given installation site.

Key-Words: - Free Space Optics, Communications, Atmospheric transmission channel

1 Introduction

The optical wireless links (OWLs) transmit an optical signal through the atmosphere. Optical power is concentrated to one or more narrow beams and optical wave can be divided into several optical channels. OWLs work mostly as a digital fully duplex links with direct intensity modulation. OWLs can work indoors or outdoors. They can be used either in deep or terrestrial space. This article is focused only on a digital fully duplex links with direct intensity modulation which work outdoors in terrestrial space. Their application is suitable in situations where the use of optical cable is impossible or desired bit rate is too high for a microwave link.

Advantages and disadvantages of OWLs follow from the basic characteristics of laser radiation and from characteristics of atmospheric transmission medium. There are four basic advantages:

- the narrow beams guarantee high spatial selectivity,
- high bit rates enable application in all types of networks,
- optical band lies outside the area of telecommunication regulators, therefore, a license is not needed for operation,
- the utilization of quantum state transmission promises long-term security for high-value data.

However there are disadvantages too:

- availability of the OWL link depends on the weather,
- OWL link requires a line of sight between transceivers,

- birds and scintillation cause beam interruptions.

For reliability improvement a number of new methods are applied: photonic technology, multi beam transmission, wavelength and space division, beam shaping, auto-tracking system, microwave backup, adaptive optics, polygonal (mesh) topology.

2 Statistical Model of OWL Links

The statistical model of OWL links serves for estimation of probability of the link interruption P_I and distribution of durations of individual fades. The total time of link interruptions T_I is defined as a time interval during which the link is not functional (bit error rate exceeds acceptable level) because of fades. The probability of such a state is

$$P_I \approx \frac{T_I}{T_M}, \tag{1}$$

where T_M is the length of period under consideration. The individual link interruption occurs when received optical power falls below the sensitivity of the receiver or when it exceeds its saturation level. The total time T_I is given as the sum of individual fade durations. With regard to the considerable difference between usual transmission rates and the processes in the atmosphere it is possible to regard the environmental influences as a slow modulation of bit error rate.

The fades are caused by many factors [4]. Long-term fades are caused by the growth of aerosol concentration in the atmosphere, in particular during autumn months when fogs are likely to occur. Other

factors include thermal deformation of transceiver consoles during sunshine. Short-term fades are usually put down to birds flying through the laser beam or to atmospheric turbulences that can cause fast fluctuations (scintillations) of received power whose dynamic range exceeds the dynamic range of receiver. The random character of received power $P_{m,RXA}$ for a link with fades is depicted in Fig. 1 [5].

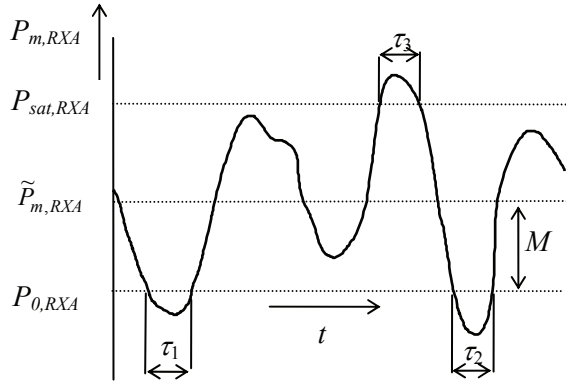


Fig. 1 Random character of received optical power for a link with fades (τ_1 , τ_2 and τ_3 - intervals where optical power on RXA exceeds receiver dynamical range).

The influence of random losses on the link power budget can be shown on the power level diagram (Fig. 2). It is convenient to measure the optical power on apertures TXA and RXA. The mean radiated power on TXA is denoted as $P_{m,TXA}$ and the power levels on RXA are denoted as follows: level of receiver saturation $P_{sat,RXA}$, received power level for standard clear atmosphere $\tilde{P}_{m,RXA}$, and level corresponding to receiver sensitivity $P_{0,RXA}$. The mean optical power on RXA is equal to $\tilde{P}_{m,RXA}$ when additional atmospheric random attenuation α_{atm} is zero.

The largest positive value of α_{atm} that does not make the received power fall below $P_{0,RXA}$ is equal to M (link margin). The lowest negative value of α_{atm} that does not make the received power exceed saturation level $P_{sat,RXA}$ is equal to $-\delta$. Negative values of attenuation α_{atm} (a kind of *gain of turbulences*) can theoretically occur due to the constructive interference of waves in the turbulent atmosphere. However, the probability of this phenomenon is very low.

The random atmospheric attenuation causes variations in the received optical power. Fig. 3 shows an example of $P_{m,RXA}$ during several days in October and November 1999. The test site was equipped with a single-beam OWL link. The path length was

$L_{12} = 750$ m and the link margin was $M = 17$ dB.

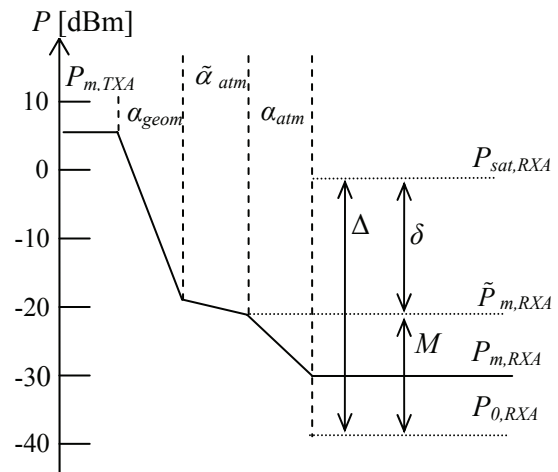


Fig. 2 Influence of random attenuation on link power budget (α_{geom} - geometrical attenuation [3], $\tilde{\alpha}_{atm}$ - attenuation of standard clear atmosphere, α_{atm} - additional random attenuation of real atmosphere).

Probability density function pdf_α of random additional attenuation α_{atm} corresponds to that of received optical power. Fig. 4(a) shows a theoretical estimation of the shape of typical probability density function pdf_α including both long-term and short-term fades [1]. A histogram obtained from our test site is shown in Fig. 4(b). A particular empirically obtained characteristic of α_{atm} depends, of course, on the geographical location of the link, path length and total period of observation.

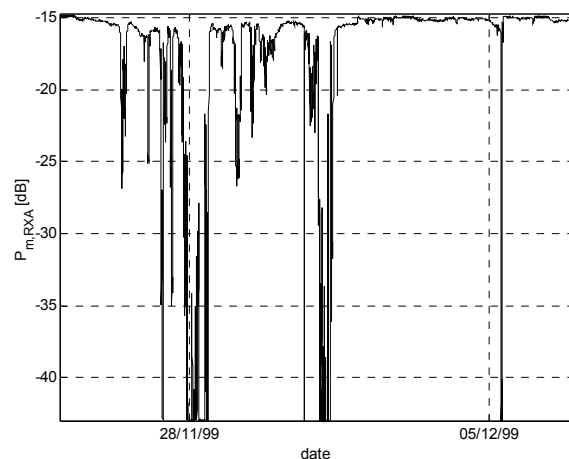


Fig. 3 Typical behavior of received power measured during period of heavy fogs.

Fig. 5 shows exceedance probability E_α [2]. This quantity determines the probability P that random attenuation exceeds the given value, i.e. $E_\alpha(\alpha_i) = P(\alpha_{atm} \geq \alpha_i)$. Its relation to classical

cumulative distribution function D_α is obvious, $E_\alpha(\alpha_i) = 1 - P(\alpha_{atm} < \alpha_i) = 1 - D_\alpha(\alpha_i)$.

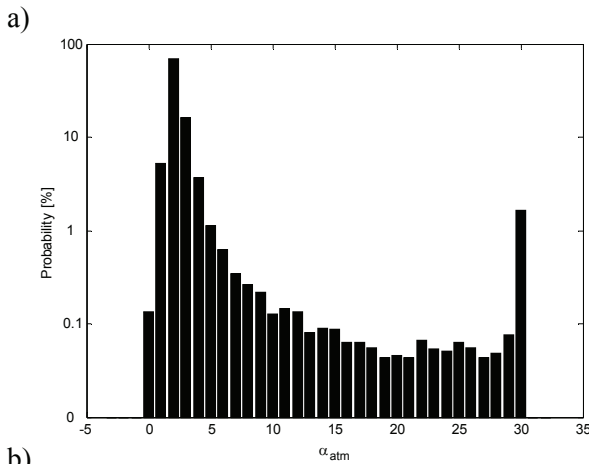
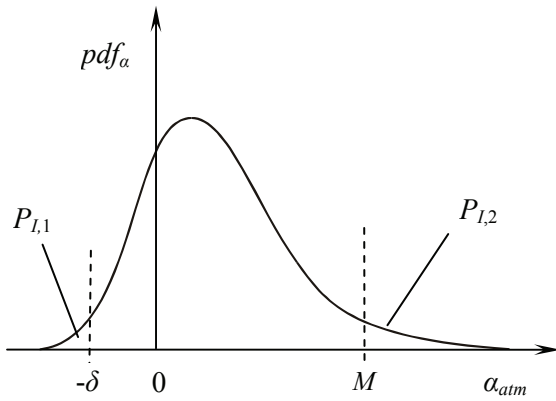


Fig. 4 (a) Theoretical shape of pdf_α [1].
(b) Estimation of pdf_α from our test site.

The link is interrupted when the received optical power exceeds the dynamic range of receiver. This event occurs with the probability (Fig. 4(a))

$$P_I = P_{I,1} + P_{I,2} = 1 - \int_{-\delta}^M pdf_\alpha(\alpha_i) d\alpha_i = 1 + E_\alpha(M) - E_\alpha(-\delta) \approx \frac{T_I}{T_M} \quad (2)$$

It is obvious that fade durations can be very different. They can practically span several orders of magnitude and their effect depends on a particular network service. Short fades (of millisecond duration) contribute to the link bit error rate and may not be even noticed by users (for a general Internet connection using the IP protocol). The longer events contribute to the link unavailability time.

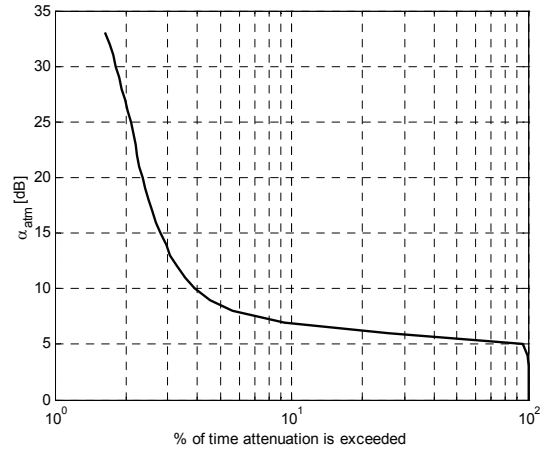


Fig. 5 Cumulative exceedance probability of random attenuation α_{atm} .

3 Estimation of Link Availability

The model of link availability estimation results from synthesis of the steady model and the statistical model. Let us assume we know parameters of OWL transceivers so that we can compute the power budget for a given transceiver distance (L_{12}). The result is the dependence of link margin (M) on the transceiver distance (L_{12}). Fig. 6 shows the diagram for particular parameters of OWL. It represents the steady model of link.

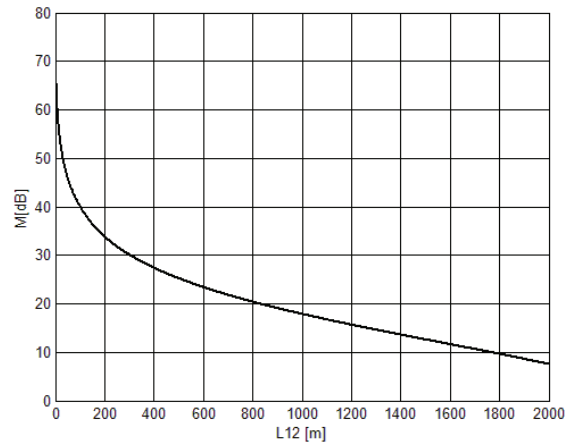


Fig. 6 The dependence of link margin (M) on the transceiver distance (L_{12}) for particular parameters of OWL.

Let us further assume we know statistical parameters of the installation site. The installation site is described by dependence of the exceedance probability on atmospheric attenuation that is shown in Fig. 5. It represents the statistical model of the installation site.

By means of synthesis of both models (the steady model in Fig. 6 and statistical model in Fig. 5) we can obtain estimation of link availability. The

procedure is as follows: First, for a given transceiver distance L_{12} we can find a normalized link margin M_1 . (The normalized link margin represents the link margin normalized to the unity distance, which is 1km.) The value of the normalized link margin also represents the greatest allowed value of atmospheric attenuation α_{atm} . (For attenuations above this level the link will be unavailable.) Secondly, in the lower figure we can find the probability of link unavailability. Obviously, the link availability is the complement value. For example, for a distance of 300m, for a particular OWL link and a given installation site we obtain link unavailability of 0.05%.

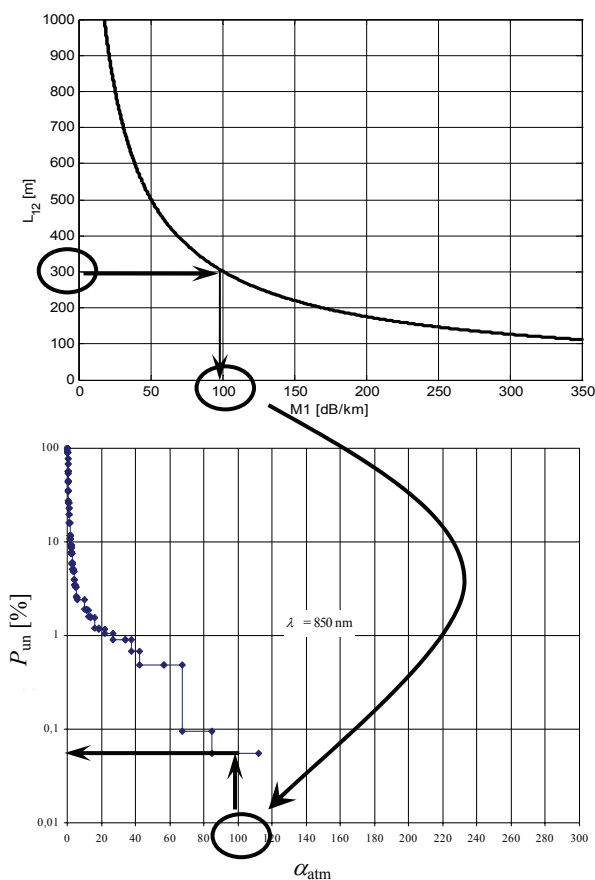


Fig. 7 Procedure for OWL availability estimation.

4 Conclusions

Steady and improvement statistical models of optical wireless links were presented. They allow an estimation of link availability based on the knowledge of the dependence of link margin (M) on the transceiver distance (L_{12}) for particular parameters of OWL and the dependence of the exceedance probability on atmospheric attenuation in given installation site.

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