Caracteristici şi cerinţe ale sistemelor optice neghidate

Characteristics and requirements of free space optical systems

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Rezumat: *Acest articol prezintă sintetic principalele caracteristici şi cerinte pe care trebuie să le îndeplinească sistemele optice neghidate pentru a-şi asigura rolul de segment optic de comunicaţii de mare viteză în cadrul reţelelor de acces actuale. Sunt examinate distanţa de transmisie versus viteza datelor şi siguranţa conexiunii, atenuarea atmosferică şi marginea generalizată a conexiunii optice precum şi parametrii de performanţă reprezentaţi de puterea de transmisie şi modulaţia folosită, rata maximă de transfer, divergenţa fascicolului optic precum şi sensibilitatea receptorului dictată de tipul de detecţie folosit.*

Cuvinte cheie: Comunicaţii optice neghidate, margine generalizată, distanţa conexiunii, rata de bit

Abstract: *This article summarizes the main features and requirements that must be assured by free space optical systems in order to secure the role of high-speed optical communications segment of current access networks. This paper examine link distance versus speed and security of data transmission connection, atmospheric attenuation and generalized link margin of optical connection and performance parameters represented by transmission power and modulation, maximum transfer rate, optical beam divergence and receiver sensitivity dictated by the type of detection used.*

Keywords: Free space optics, generalized link margin, link distance, bitrate

1. **INTRODUCTION**

FSO provides a flexible solution for network technology that can easily sustain broadband communications. Several reasons can be given for the choice of the FSO connections. One of the reasons is legal nature, in that, in contrast with radio links, are not necessary authorizations or licenses for frequencies. There are also economic reasons, dictated by the fact that the installation of such a type of network is easy, fast and less expensive than installing a wired optical networks.

Because FSO equipment transceiver can transmit and receive signals through the windows of the buildings, the system can be easily installed inside buildings while avoiding the necessity of its attachment to the roof, making it this way the wiring and equipment allowing it to work in a conducive environment. The only condition to fulfill is the direct line between transmitter and an optical receiver.

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An advantage of the free space optical communications is represented by the fact that, in the case of a combined guided optical communications (fibre) and FSO are no longer necessary OEO conversion equipment. For example, WAN communications and metro can be made using fiber optics, and the "last mile" of the local networks using FSO. It greatly simplifies the connection, there will be no conversion equipment in the field of optical electric field and vice versa, and field gear is perfectly comparable.

Advantages of the free space optical communications cannot be highlighted without the presence of certain costs. When light is sent through the optical fiber, for example, the integrity of the transmission is predictable. When light is sent through the air, as is the case of FSO, must take into account a complex environment and not always predictable and quantifiable-terrestrial atmosphere. The challenges are numerous and the FSO shall take into account:

✓ **Foggy weather phenomenon**, which is what softens the visible radiation and has substantially similar effects in the near infrared. It is worth noting that the thick haze is a phenomenon that can interrupt the communication methods that can counteract its effects partly;

✓ **Various weather phenomena** (rain, hail, drizzle, snow);

✓ **Physical obstructions** caused by birds or objects into the air. Due to the fact that these transmitters are multispot, this NOT cause the interruption of the connection;

✓ **Stability of piles** - most of the FSO systems are affected by movement. The existence of automated systems of alignment offsets this phenomenon, as well as the divergence of the beam controlled optical field of view received pairing (FOV);

✓ **Scintillation phenomena**. They occur in very sunny days and the effects are reflected in the statistics of the BER factor. The received signal fluctuates rapidly with frequencies between 0.01 and 200 Hz wave fronts vary like causing optic beam focus and defocalizing. This can be avoided by using high-quality optics, filtering systems and receiver automatic gain control/AGC;

✓ **Scattering phenomena** caused by the interaction of the radiation which has a certain wavelength with particles called "scatters". When the physical size of the scatter is less than the wavelength we are dealing with the Rayleigh scattering. When scatter in size is comparable with the wavelength we are dealing with scattering, and lastly, if the size of scatter is much higher as the wavelength we are dealing with non-selective Raman scattering;

✓ **Solar radiation interference** with systems operating at 1550 nm. This type of interference can be countered through the use of an optical filter to block the narrow radiation under 850 nm and to let pass only the wavelengths used in communication intersistem. It also foresees the spatial filters that don't let them pass the incident radiation entering the receiver at an angle of more than 1.5 degrees.

2. **DESCRIPTION OF THE PROBLEM**

Requirements of the FSO systems:

2.1) **The transmission distance and atmospheric conditions**

This transmission distance varies from a few tens of meters to several kilometers. Some manufacturers specified maximum working distance, the maximum distance specified for various atmospheric conditions, others propose a recommended distance for which the signal is kept within certain limits [1],[2]. These values should not be construed as absolute values.

2.2) **Safety**

An important factor is the category which includes laser because it dictates the ease of installation and subsequent maintenance of the equipment. Parameters to be taken into account when we define the category to which it belongs are laser wavelength, power and beam shape. Also, the light radiation must not impair human vision.

Since the initial spot has a diameter of a few centimeters and after a few kilometers reach 4-6 m [3], and communication can be of roof-roof, roof-window or window-window is necessary to select a wavelength that does not affect human vision.

2.3) **Modulation format**

The FSO system design must take into account the optical signal modulating the optical source for the purpose of generating the logic levels "0" and "1". The type of modulation used is "ON-OFF keying" OOK and PPM with his variants. When data is sent, the logic "1" is the existence of a short optical pulse and the logic "0" by absence [4], [5]. [12].

2.4) **Bitrate and type of recommended applications**

Many FSO systems are transparent to transfer rate and transit protocols. FSO operates on level 1 of the OSI model just like a wireless radio repeater. He can, however, carry higher-level protocols. Apps are the maximum capacity the system can transmit a transparent system that can carry (usually) up to 2 Gbit/s, for example, will be able to transmit streams STM-1, ATM, FDDI, and Fast Ethernet. In other cases, equipment is specified for a certain rate of transfer or a particular type of interface, for example E1 (2.048 Mbit/s) or GB-Ethernet (1000 Mbit/s).

2.5) **The wavelength** at which the optical link operates and the type and number of optical transmitters. Usually the wavelength is situated around 1500 nm. These parameters influence the link margin (measured in dB) that have designed the system and have a major influence of the quality of service [6].

2.6) **Link margin**

The most important parameter in describing performance of a FSO connection is the link margin [11]. This represent the amount of light above and below the level needed to keep the connection active (hence the term "link margin"). For example, if a receiver has to "see" the minimum optical input power 5 nW to maintain an active connection when you will receive 500 nW then link margin (reserve) will be 20 dB. This means that 99% of the transmitted power can be absorbed by the atmosphere before the link to become non-functional. The link margin is measured in dB.

An important concept is that of "dynamic range" of a FSO system. The dynamic range is defined as the difference between maximum and minimum power levels that FSO system can accept. It is very important for a system to detect small signal levels, but also tolerate very strong optical signals that can cause problems by saturating the receiver.

This issue manifests in short optical links where the signal is attenuated with a very little amount in atmosphere. The dynamic range is measured in dB and is a comparison of two values. For example, a dynamic range of 30 dB means that the maximum signal (from which the receiver enters into saturation) is 1000 times greater than the minimum detected signal (receiver sensitivity).

The higher dynamic range is greater, the more robust and versatile FSO system, meaning that it can support a wide range of atmospheric conditions. It is not enough to define the link margin, but you must also specify the dynamic range and worst case that can evolve weather conditions.

3. PERFORMANCE ANALYSIS

To describe the performance parameters of a system (FSO) must define some terms:

- ***Transmission power***

Due to the fact that the power output is given by the intrinsic characteristics of the laser transmission power is defined as power measured at the output of the laser. If you are using multiple lasers, total power is the sum of them. And losses are to be the optical transmission system.

- ***Optical beam divergence of the transmitted signal***

Power profile that defines the optical beam is not constant over the entire spotlight, but has a Gaussian distribution. Basically, the optical energy is concentrated on so called called divergence FWHM (full width half maximum) of the optical beam.

.• ***Receiver sensitivity***

Similar power returned, the sensitivity is measured directly at the receiver (is). This means that the efficiency of the reception should be defined taking into account the loss of incoming beam surface and the receiver himself.

Sensitivity is defined as the minimum detectable power optical receiver under the conditions of maintaining a minimum BER 10^{-6} [7].

- ***Generalized link margin***

This section will discuss the issue of the relationship between the noise, dynamic range and the parameters that characterize the connection.

According to [10], the power received can be written as:

$$P_{received} = P_{transmitted} \cdot \frac{L \cdot D^2}{d^2 \cdot R^2 \cdot 10^6} \cdot 10^{\left(\frac{-aR}{10}\right)} \quad (1)$$

where:

P = power [mW]
L = optical transmission/reception losses [%/ 100]:
D = receiver diameter [m]
d = beam divergence [rad]
R = distance between transmitter-receiver [Km]
a = attenuation [dB/Km].

The values for attenuation factor [dB/km] is found in International Visibility Code. Some representative values are founded in table 1.

Table 1 Atmospheric conditions and their corresponding visibility and attenuations

Conditions	Visibility [m]	Attenuation [dB/km]
Clear-sky	10000 - 50000	0.2 - 3
Rain	1000 - 10000	2 - 20
Snow	500 - 5000	4 - 30
Fog	10 - 1000	28 - 300

The ratio between received power and minimum required power from the receiver (denoted by its sensitivity) can be expressed in dB as follows:

$$\text{Link margin} = 10\log\left(\frac{P_{received}}{s}\right) \quad (2)$$

Link margin is an advanced method that take into account of distance (maximum) of the link and the atmospheric conditions. Then, according to [11], we can write the relationship:

$$\text{Link margin} = 1 - \log\left(\frac{P_{transmitted} \cdot LD^2}{sd^2} \cdot \frac{10^{\left(\frac{-aR}{10}\right)}}{R^2 \cdot 10^6}\right) =$$

$$= \underbrace{10\log\left(\frac{P_{transmitted} \cdot LD^2}{sd^2}\right)}_{\substack{\text{SYSTEM PARAMETERS} \\ \text{(TRANSMITTER}-\textit{RECEIVER}\text{)}}} + \underbrace{10\log\left(\frac{10^{\left(\frac{-aR}{10}\right)}}{R^2 \cdot 10^6}\right)}_{\substack{\text{LINK PARAMETERS} \\ (\textit{DISTANCE} \text{ AND METEO CONDITIONS})}} \quad (3)$$

Link margin (3) can be regarded as a sum of two completely unrelated factors: one involves specific conditions of connection, another involves factors that are related to the system itself [8].

Parameters relating to connection are essential in evaluating the attenuation for a given connection (particular connection). The other parameters (system) reflects the extent to which the system can compensate for this mitigation. Neglecting the term related to the parameters of the connection, we can write the expression of link margin [11]:

$$\text{Generalized margin} = 10\log\left(\frac{P_{transmitted} LD^2}{sd^2}\right) \quad (4)$$

Figure 1 depicted optical power budget of the FSO link with the link margin and receiver sensibility threshold.

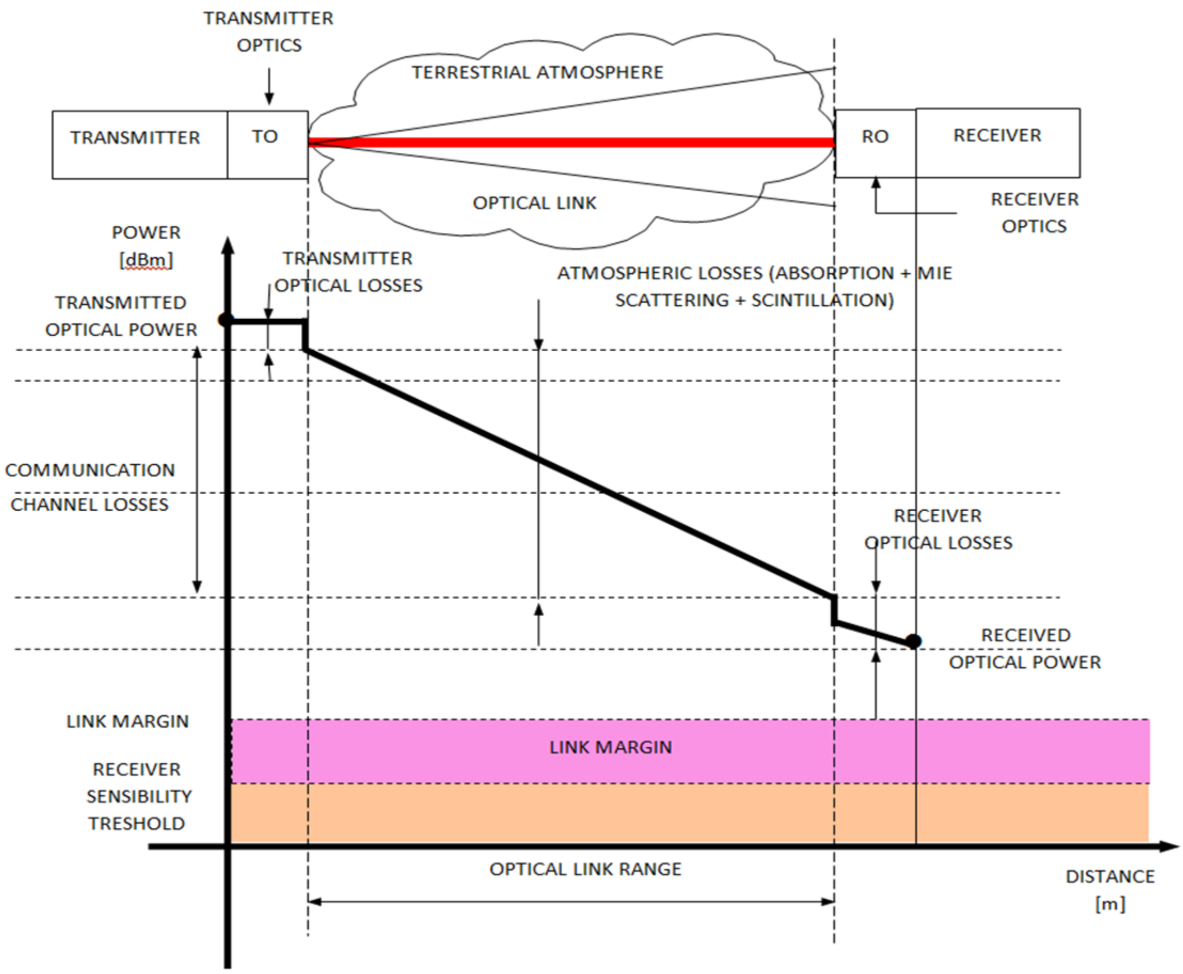

Fig. 1 Optical power budget of the FSO link

Other secondary parameters that we must take into account:

- The possibility of controlling the alignment which must provide protection against shocks and vibrations (dynamic recalibration);
- Simple process of implementation and maintenance;
- Software enabling the link elements and management of devices involved in a single location;
- Automatic systems for optical beam interruption in the event of detection, for example, of intruders that access the transmitted data stream (security reason);
- The cost of the entire system;

4. **CONCLUSIONS**

Generalized link margin provides a standard for evaluating and comparing various systems independent of the maximum distance of the link, or atmospheric conditions. Its calculation is derived from the relationship of the link margin and account for all significant parameters that define the performance of the system [9]. Generally, a system is chosen for a specific application, in order to provide a certain level of performance in the most adverse atmospheric conditions. The availability of a FSO connection refers to the length of time a link is operational and is expressed as a percentage. As an example, a 99.9% availability (the three "nine") means that the link may not be operational at most 43 minutes every month or 8.6 hours per year. Availability of 99.99% means that the connection might not be operational no more than 4 minutes per month, or a total of 52 minutes per year [10].

Turbulence produce fluctuations in amplitude and phase optical signal received, degrading the overall performance of the connection. FSO communication channel must be modelled to take into account the factors that influence the level of performance.

Mist, fog, rain, snow, sunlight interfering with the absorption, scattering and flicker are processes that degrade inherent optical connection quality. These phenomena are manifested in both the visible spectrum and the infrared windows that represent the common usage of optical transmission. Atmospheric Turbulence causes the received signal level fluctuations, which can increase the bit error rate in digital communications systems.

The FSO systems are affected by absorption and scattering phenomena that emerge through the interaction between optical wave and terrestrial atmosphere. Optical beam interacts with a wide variety of small particles suspended in the atmosphere. The interaction produces a variety of effects: frequency selective absorption, scattering and scintillation.

Quantification of attenuation is subject to fluctuation in intensity due to the types and levels of atmospheric turbulence. Particles in the atmosphere are randomly distributed under temperature gradient effect that appears along the propagation environment. Variation of wavelength caused by the distribution of these cells, produce defocalizing of the optical beam.

The amplitude and frequency of scintillations depend on the relationship between particle size and diameter of the optical beam. The intensity and frequency of scintillations grow with photon wave frequency. FSO faces with problems of noise related to optical beam passing through the terrestrial atmosphere.

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