A new Quality of Service FSO software

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Abstract:

Free space Optical links (FSO) in visible and infrared wavelengths constitute an interesting alternative to new transmission channels for cordless phone, data-processing networks and high definition television, etc. This telecommunication technology presents numerous advantages: no interferences, no license, easy installation, high data rate (from several Mbits/s to several Gbits/s at short distance), low cost, recoverable and moveable systems, etc.

Availability and reliability of a FSO link depend on used systems but also on climatic and atmospheric parameters such as rain, snow or fog. The aim is to present a light version of a new quality of service FSO software which allows predicting, starting from the data of equipment (power, wavelength, receiver sensibility), geographical situation of a site in Europe (geographical coordinates, altitude, height/ground) and climatic and atmospheric parameter (relative humidity, ground rugosity, albedo, solar radiation, etc) the availability of a FSO link for the following period (year, the most unfavourable month, 8am to 8pm period and 8 pm to 8 am period. The interruption probabilities for each type of attenuation are also mentioned (aerosols, scintillation, ambient solar light, rain, snow, etc).

1 - Introduction

The atmospheric optical links (FSO) in visible and infrared wavelengths constitute an interesting alternative for a variety of applications in telecommunications field. Several factors determine the revival of such technique: absence of regulation, free licence, easy, fast and inexpensive deployment and high data rates.

Before to implement an effective FSO links, we need to know their availability and their reliability (percentage of time during which a value is reached or exceeded). It is the purpose of our study. Its finality is a software which integrates results of a library search (geometrical attenuation, aerosols, scintillation, environment light, etc) and European integrated surface weather data, hour per hour, over several years (1995-2002).

The result is the presentation of a new Quality of Service light version software, allowing to predict, from the data of equipment (power, wavelength, receiver sensibility), geographical situation of a site in Europe (geographical coordinates, altitude, height/ground) and climatic and atmospheric parameter (relative humidity, ground rugosity, albedo, solar radiation, etc), the availability of a FSO link for the following period (year, the most unfavourable month, 8 am to 8 pm period and 8 pm to 8 am period. The interruption probabilities for each type of attenuation are also mentioned (aerosols, scintillation, ambient solar light, rain, snow, etc).

2 – System variables

Performances characteristics of a free-space optical data links depend upon the atmosphere in which they propagate. The two principal mechanisms of deterioration of such transmission are:

- The overall reduction of the detected optical power level due to geometric, atmospheric (molecules, aerosols (fog particularly), rain, snow) and ambient light attenuation (solar radiation).
- The power fluctuation of the signal at the receiver due to scintillations of the medium refractive index.

The optical link margin is the power available above the sensitivity of the receiver. The following relation defines it:

$$M_{link}\,(dB) = P_e + S_r - Att_{Geo}(dB) - Att_{Atm}(dB) - P_{tot}(dB)$$

where:

- P_e is the total power of the emitter (dBm)
- S_r is the sensitivity of the receiver (dBm)
- Att_{Geo} is the link geometrical attenuation (dB)
- Att_{Atm} is the link molecular attenuation (dB)
- P_{tot} (dB) are others system losses

2.1 - Geometrical attenuation

The beam emitted by the transmitter being diverging (1-3 mrad), the receiving cell will collect only a part of emitted energy. The following relation gives the geometrical attenuation:

$$Att_{geometrical} = \frac{S_d}{S_{capture}} = \frac{\frac{\pi}{4}(d\theta)^2}{S_{capture}}$$

where:

- S_d : Spot surface at the distance d,
- $S_{capture}$: Receiver capture surface (0,005 m^2, 0,025 m^2 for example),
- θ : Beam divergence,
- d : Transmitter-Receiver distance.

2.2 - Atmospheric attenuation

Atmospheric attenuation results from an additive effect of absorption and dispersion of the infrared light by aerosols and gas molecules present in the atmosphere. Transmittance in function of the distance is given by BEER relation:

$$\tau(d) = \frac{P(d)}{P(0)} = e^{-\sigma d}$$

where:

- $\tau(d)$: Transmittance at the distance d of the transmitter
- P(d): Power of the signal at a distance d of the transmitter
- P(0): Emitted power
- σ: Specific attenuation or extinction coefficient per unit of length

The extinction coefficient σ is the sum of 4 terms:

$$\sigma = \alpha_m + \alpha_a + \beta_m + \beta_a$$

where:

- α_m is the molecular absorption coefficient (N_2, O_2, H_2, HO, CO_2, O_3,..),
- α_a is the absorption coefficient by the aerosols (small solid or liquid particles present in the atmosphere (ice, dust, smoked, …),
- β_m is the Rayleigh scattering coefficient resulting from the interaction of the wave with particles of size smaller than the wavelength,
- β_a is the Mie scattering coefficient. It appears when particles are of the same order of magnitude as the transmitted wavelength.

Absorption dominates in the infrared while scattering dominates in the visible and ultraviolet band. Being given the low values of molecular and aerosols absorption coefficients as well as Rayleigh scattering coefficient, extinction coefficient can be written by the following relation:

$$\sigma \cong \beta_n = \frac{3.91}{V}\left(\frac{\lambda_{nm}}{550}\right)^{-Q}$$

where:

- V is the visibility (km)
- λ is the wavelength (nm)
- Q is the size distribution of the diffusing particles:
  - = 1,6 for strong visibility (V>50 km),
  - = 1,3 for average visibility (6<V<50 km),
  - = 0.16V + 0.34 for visibility (1 km<V<6 km)
  - = V - 0.5 for visibility (0.5 km<V<1 km)
  - = 0 for low visibility (V<0.5 km).

The visibility is a concept defined for the meteorology needs to characterize the atmosphere transparency and estimated by a human observer. It is given by the Atmospheric Optical Range and measured using a transmissometer or a diffusiometer.

Molecular attenuation is function of the wavelength used. Some typical values are 0.13, 0.01, 0.41 and 0.01 dB/km at 550, 690, 850 and 1550 µm respectively.

Visibility statistics are described from integrated surface hourly climate weather data edited by National Weather Administrations.

2.3 - Rain attenuation

Attenuation due to rain, independent of the wavelength, is a function of the precipitation intensity R (mm/h) according to the following relation [1]:

$$Att_{rain} = 1.076 * R^{0.67} (dB/km)$$

Rain intensity is the fundamental parameter used to locally describe the rain. Its measurement is carried out either directly by means of pluviometers or weather radars.

Characteristics of precipitation for propagation modelling are published by ITU-R (precipitation map, statistics of precipitation intensity) [2]. Computer program, give the rainfall rate, R_p, exceeded for any given percentage p of the average year for any location. Knowing the link margin deduced from the optical power link budget, we can deduce, by dichotomy, the interruption probability of the link due to rain.

2.4 - Snow attenuation

Attenuation due to snow is a function of the wavelength (λ_{nm}) and precipitation intensity S (mm/h) according to the following relations:

- Wet snow (altitude <500m): $Att_{snow} = (0.0001023 * \lambda_{nm} + 3.7855466) * S^{0.72} (dB/km)$
- Dry snow (altitude > or = 500 m) $Att_{snow} = (0.0000542 * \lambda_{nm} + 5.4958776) * S^{1.38} (dB/km)$

Snow intensity S is the fundamental parameter used to locally describe the snow. Its measurement is carried out in meteorological station. Characteristics of snow precipitation are derived from those of rain precipitation in function of system altitude. A weighting coefficient, function of altitude (km), is applied to rain rainfall rate, R_p, exceeded for any given percentage p of the average year for any location. Knowing the link margin deduced from the optical power link budget, we can deduce, by dichotomy, the interruption probability of the link due to snow.

2.5 - Ambient light attenuation

Solar conjunction occurs when the sun or a reflected image of the sun is in or near the instantaneous field of view of an optical receiver (IFOV). The receive IFOV is generally at least as large as the transmit divergence. We calculate the probability for which the sun position is parallel to the optical link and the sun power penetrating inside the receiver is greater than the power received from the emitter.
The power radiated by the sun (Watts/m^2) is defined by the following relation:

$$Power\_radiated = 1200 * \cos\left(\frac{\pi}{2} - Elevation_{radian}\right)$$

where:

Elevation$_{radian}$ is the sun height.

The power penetrating inside the receiver is given by the following relation:

$$P_{solar} = F_{solar} * Power\_radiated * Capture\_surface * Width\_band_{receiver(nm)} / 100$$

where:

- F_{solar} is a wavelength function characterising the sun spectral power,
- Capture_surface is the receiver capture surface,
- Width_band $_{receiver(nm)}$ is the receiver width band.

2.6 - Scintillations effects

Under the influence of thermal turbulence within the propagation medium one attends the formation of random, variable size (10 cm – 1 km) and of different temperature cells. These various cells have different refraction indexes thus causing scattering, multiple paths and arrival angle variations: the received signal quickly fluctuates at frequencies ranging between 0.01 and 200 Hz. The wave front varies in a similar way causing focusing and defocusing of the beam. Such signal fluctuations are called scintillations. Scintillation amplitude and frequency depend on the cells size compared to beam diameter. When heterogeneities are large compared to the beam cross section, it is deviated, when they are small, beam is widened.
The tropospheric scintillation effect is generally studied starting from the logarithm of the amplitude χ [dB] of the observed signal ("log-amplitude"), defined as the ratio in decibels of its instantaneous amplitude and its average value. Intensity and speed of the fluctuations (frequency of scintillations) increase with the wave frequency. For a plane wave, a weak turbulence and a specific receiver, the scintillation variance $\sigma 2\chi$ [dB^2] can be expressed by the following relation:

$$\sigma_\chi^2 = 23.17 * k^{7/6} * C_n^2 * L^{11/6}$$

where:

- k [m-1] is the wave number,
- L [m] is the link length,
- $Cn^2 [m^{-2/3}]$ is the structural parameter of the refraction index representing the turbulence intensity. It is a function of roughness, solar radiation, humidity and terrestrial albedo.

Scintillation peak-to-peak amplitude is equal to 4σ and attenuation related to scintillation is equal to 2σ.

3 – Quality of Service software

This software is a statistical tool made up of a GUI (Graphical User Interface) and a kernel of calculation here previously described. It allows evaluating the quality of service of an atmospheric optical link in term of probability of connection and cut-off time. It is composed of three windows: the capture data window, the report window and the graphical window.

3.1- Capture data window

It permits to the user to introduce the links characteristics. It is divided into six blocks of items: Data Sites block, Equipment block, Common Sites Data, Common Equipment Data, Environment and Information. The five first blocks have to be filled by the user. The Information block fields are calculated by the software.

3.2 - Report window

It give the simulation results. It is divided into four blocks of items: Pathloss, Meteorological phenomena, Availability and Data Sites block: Equipment Data block, Common Sites Data block, Common Equipment Data block, Environment block, Information block (cf fig. 1).

3.3 - Graphic results

Results are also graphically presented: Annual interruption probabilities, availability (aerosol + max (rain, snow) , unavailability (number of yours), attenuation values (cf. fig. 2).

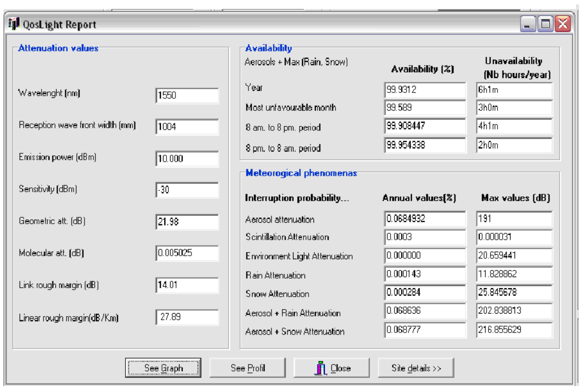

Figure 1: Report window

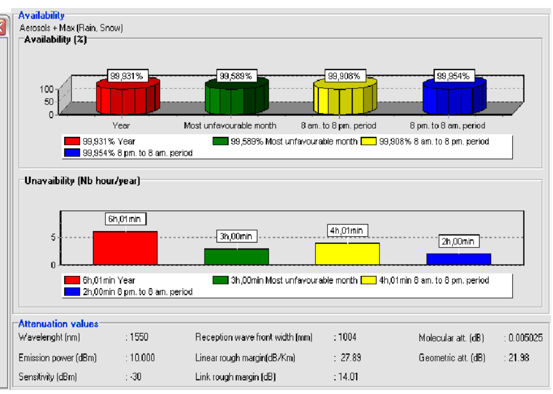

Figure 2: Graphical window

4 – Conclusion

We have presented the different functionality of a quality of service software dedicated to prediction. The result is the presentation of this software, allowing predicting the availability of a FSO link for different period (year, unfavourable month, 12 hours day period. He starts from the data of equipment (power, wavelength, and receiver sensibility), geographical situation (geographical coordinates, altitude, and height/ground) and climatic and atmospheric parameter (relative humidity, ground rugosity, albedo, solar radiation, etc). The interruption probabilities for each type of attenuation are also mentioned (aerosols, scintillation, ambient solar light, rain, snow, etc). The last ones have been detailed. The use of such computer program should make possible to show that free-space optical links can constitute a reliable broadband to the optical fiber installation and lead to a better acceptance of this technology in the industry of the high data rates telecommunications networks. For more detail concerning propagation and communication in Free Space Optics, the reader can refer to the literature[3], [4].

5- References

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