The New Statistical Model for FSO Systems

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***Abstract* - FSO technology is a progressive implementation of smart network solutions these days. The link speed, low cost, a fast implementation are just a few advantages of many other. Despite all those strengths there is at least one limitation. It is called weather. The wavelengths values on which FSO operates are quite similar to fog, smoke, snow and dust particles. It is obvious that if those proportions are comparable, it's not surprising that there will be some interactions among beams and particles. That's why we decided to investigate the weather influence to a link availability of FSO at our location in Kosice, Slovakia. To accomplish this we used fog sensor and wrote a simulating program for data processing. The industries as well as universities are already trying to solve the problems when FSO link is not working out because of low visibility. There is already the hybrid equipment on the market which serves as an additional component (an enhancement) by using RF (Radio Frequency) waves.**

Keywords—FSO link; link availability, statistical model FSO

I. Introduction

In general the FSO – Free Space Optics is a modern and a fast growing signal transmission technology. This technology was primary used and developed for the needs of the American army. It did not take a long time and the commercial market took its place. Nowadays FSO is used quite widely in television market and the main purpose is usually live streaming [1]. FSO is basically the laser beam connection between two nodes. For better imagination we could describe this link as two cameras which are placed on higher locations (tall buildings, hospitals, university campuses). One of the most important conditions for FSO smooth operating is a direct visibility and a clean atmosphere. By passing these conditions the full duplex FSO link is able to work with speed around 1.25 Gbps. The distance is usually within 4 km. There is an ambition to develop link which will reach the speed around 10 Gbps. The FSO are fully implementable in the existing network infrastructure and have absolutely no problem with an acceptance of any internet protocols [2]. FSO link is able to transfer almost any kind of common used data – video, audio as well as information data. FSO systems are designed to operate on wavelengths λ within interval from 850 nm to 1550 nm with correspondence frequency around 200-300 THz.

The frequencies higher than 300 GHz do not need to be licensed so far which is a great advantage of FSO links [2,6].

FSO is also called point–to–point link and both nodes are simultaneously receiver and transmitter at the same time. The FSO communicates thought the laser beam. It is obvious that the scientists aim is also considered to shape laser beam as thin as possible due to beam divergence on a long distance (Fig. 1).

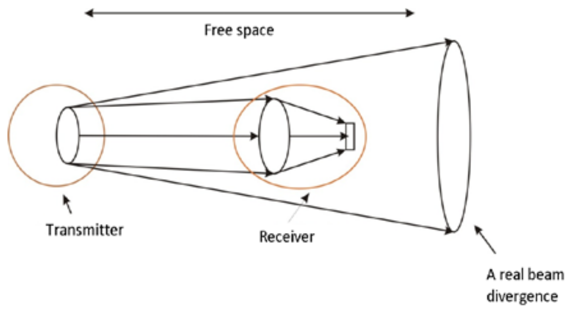

Fig. 1. Simple FSO architecture

The FSO cameras have to be fastening strong. To achieve this goal is not an easy task. It was already mentioned the FSO requires a direct visibility from one node to another. A physical barrier like objects in the air, trees, smoke, dust, etc. will absolutely cause the signal degradation and in the worst case a link interruption.

II. Free Space Optics in use

A. FSO strengths

Commercial FSO link is working with wavelength λ 850 nm – 1550 nm. Those two values are also called "atmospheric windows". Those values were picked for a special purpose, in other words the atmospheric windows have a special attribute not to support absorption of a transmitted signal. The same idea regarding to mentioned wavelengths is also used in optical fibres [3].

Among the main FSO advantages belong:

- flexibility,
- a high speed communication channel,

- a high security,
- a resistance against the RF interference, etc.

B. FSO weakness

Despite the fact that FSO has numerous advantages is has some limitations as well. Perhaps the most critical degradation factor is weather – its negative atmospheric influences. The rain, snow and fog are essential indicators which have a meaningful impact on FSO link. Another negative factor is atmospheric turbulences which are caused because of temperature and pressure changes. Fluctuations well known as fades appear simultaneously with turbulences and also have a significant effect on FSO link. Both turbulences and fluctuations are increasing BER (Bit-Error-Rate). During last few decades were developed couple of statistical methods to describe the influence of weather conditions on FSO link [3].

III. Statistical Models

One of the most common used statistical models is called Log-normal model (LN). This model takes its place in weak atmosphere conditions and it often occurs in performance analyzes. By using LN model is possible to calculate BER and to evaluate FSO link. The analytic expression of BER for LN is not easily get in open literature that's why it is described with Gauss–Hermite polynomial functions or by using Monte–Carlo simulation. The goal of those analyses is to picture some acceptable distributions of LN which will simulate the fluctuations in weak atmosphere conditions. The avalanche diodes are usually used for simulations on the receiver side. One of the basic things which is needed to define is the fluctuation condition is Inverse - Gauss model (IG). This model estimates LN model [3,6].

A. Turbulations regarding to IG model

The fluctuations can be modelled through the IG model. A probability density function (*pdf*) as a function of distributed radiation *I* is calculated regarding to (1):

$$f_I = \sqrt{\frac{\lambda}{2\pi I^3} e^{-\frac{\lambda(I-\mu)^2}{2\mu^2 I}}}, I > 0 \tag{1}$$

where $\mu > 0$ is a fluctuation parameter and $\lambda > 0$ is a scale distribution parameter.

B. IG and LN model approximation

The Kolmogrov-Smirnov statistical method shows us how to compare IG and LN models. The results value gives us a maximum absolute value of a difference between cumulated distribution function (*cmd*) of IG and the LN model. This difference is expressed in (2):

$$T \cong \max\left|F_x(x) - F_y(y)\right| \tag{2}$$

where $F_x(x)$ is represents *cmd* of IG and $F_y(y)$ is a *cmd* of LN model.

C. Statistics used in experimental software

The different statistical approach to the FSO link was investigated at the Technical University of Košice (TUKE). The university has bought equipment – fog, temperature and humidity sensor all in one gadget. This sensor has been measuring and gathering data for couple of years. For the experiments we decided to pick one year of records (2011).

At first it is needed to talk about the statistical dependencies and the factors which have a significant impact on FSO link in our location Kosice, Slovakia. To implement the calculations into the software which was written in C#, we have to deal with attenuation in its various atmospheric forms.

D. Absolute attenuation

It's been already mentioned that the weather conditions (fog, show and rain) have the most negative influence on FSO systems. An attenuation α is an important factor which is a part of the atmosphere and it plays a considerable role regarding to FSO link.

The total attenuation consists of two partial elements α_{atm} and α_{geom} as shown in (3).

$$a_{total} = \alpha_{atm} + \alpha_{geom} \tag{3}$$

where α_{atm} is an atmospheric and α_{geom} represents a geometrical attenuation.

E. Atmospheric attenuation

The total atmospheric attenuation is a sum of two partial components. The first one is caused by moving of particles in atmosphere and it is signed as α_{part}. The particles attenuation can be expressed (4) if we think about the stationary and homogenous atmosphere.

$$\alpha_{part} = \alpha_{1/part} \cdot L_{12}[dB] \tag{4}$$

The second part of the atmospheric attenuation is called turbulence attenuation α_{turb}. We can get this value from the practical measurements. In other words turbulence attenuation is obtained empirically. The approximation of the α_{turb} is shown in equation (5):

$$\alpha_{turb} \approx \left|10\log\left(1-\sqrt{\sigma_{r,l}^2}\right)\right|[dB] \tag{5}$$

where parameter $\sigma_{r,l}^2$ is a relative variance of the optical intensity. This parameter is calculated from the distance between the optical nodes L_{12} and a coefficient C_n^2.

F. Geometric attenuation

Geometric attenuation also occurs on the way between FSO cameras. This kind of attenuation depends on the lens diameter D_{RXA}, D_{TXA} of transmitter and receiver as well as the distance L_{12} between nodes [4,5,7]. The particular formula is shown (6). The geometrical attenuation is basically the difference between the attenuation which appears when signal is propagating α_{12} from one FSO node to another one and the gain of a receiving aperture γ_{RXA}.

$$\alpha_{geom} = \alpha_{12} - \gamma_{RXA} = \left| 20 \log \frac{D_{RXA}}{D_{TXA} + \varphi_t L_{12}} \right| [dB] \quad (6)$$

G. Margin

A margin M is another important parameter which is needed to be considered when calculating and evaluating FSO technology. It gives us information wheatear the FSO is available. It is a kind of limit and its value is given in [dB]. A numerical margin value is possible to get from the, (Fig. 1). The result – a margin is represented as the difference of two experimentally gathered curves. Those are the distance functions $f_1(L_{12})$ and $f_2(L_{12})$[3].

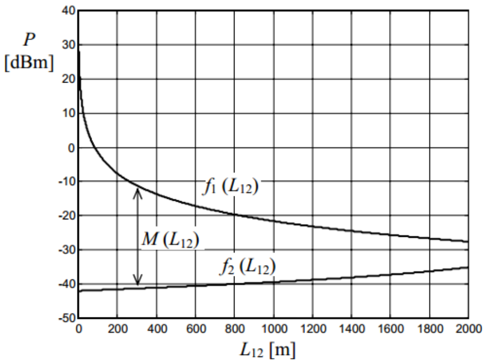

Fig. 2. Margin empirical calculation [8]

IV. Experiments and measurements

The experiments and simulations were done in the experimental simulating program. We used the data from fog sensor which was collecting data (fog, humidity and temperature) during one year. The strategic values, we used to determinate the availability of FSO link, were fog values. By reaching the critical fog density values, it means when the fog is too thick and a laser beam is not able to overcome such layer which causes that FSO link is not working anymore. To simulate such situation we needed to convert fog values from our sensor. Sensor gave us values in raw form and those were needed to be converted to fog density g/m^3. To achieve that we used "Static model" – experimental software which considers all attenuations mentioned above, wavelengths and margin included.

A. Calculations

The provide simulations in an experimental software we had to define an upper fog density value by which the FSO link is still able to operate. It is basically a number which will decide whether FSO connection is up or down. It mainly depends on the distance-visibility, wavelength and attenuation (7).

$$V = b \cdot LWC^{-0.65} [km] \quad (7)$$

A value b is a specific parameter which specifies various weather conditions. For our experiment we used the value 0.024 because it is the most proper for our weather conditions. LWC is a particular fog density value and V is distance-visibility. From equation (7) comes the reference fog density value as show on (Fig. 3). It is represented by a red line. For the link availability is then counted every value which is up the red line. The final link availability is then expressed as the ratio of the time when a link was not available T_I and the total time when FSO link was up T_M as shown in equation (8):

$$P_I = \frac{T_I}{T_M} [\%] \quad (8)$$

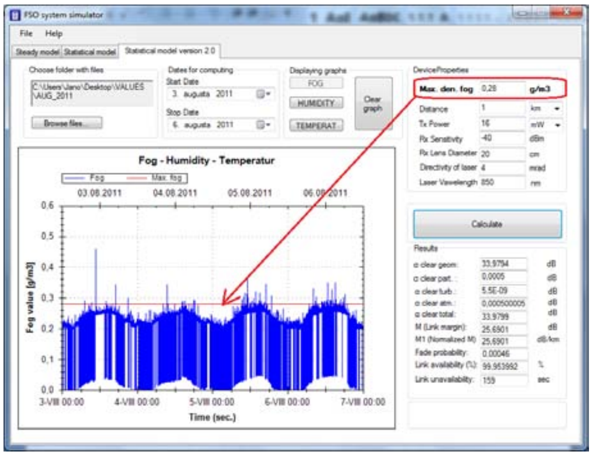

Fig. 3. Experimental simulating software.

We made a bunch of measurement per every month of year 2011 by using our simulating program. The simulated distance between FSO nodes has been increasing constantly from 1-4 km. All the results are shown in the following charts (Fig.4, Fig.5, Fig.6, and Fig.7).

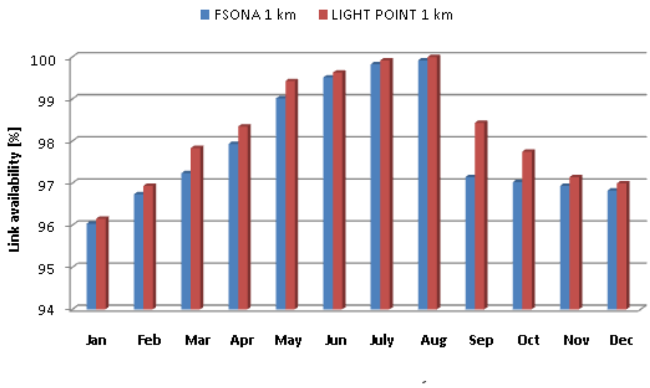

Fig. 4. Link availability, distance 1 km, FSONA, LIGHT POINT (2011).

It is also important to note that our university owes two pairs of FSO nodes from two different brands LIGHT POINT and FSONA. The cameras from LIGHT POINT are working with wavelength λ 850 nm and FSONA's nodes operate within 1550 nm. The wavelengths were also used as the essential values for calculating of a final LWC value by using other experimental software called "Static model" which was also made at our university.

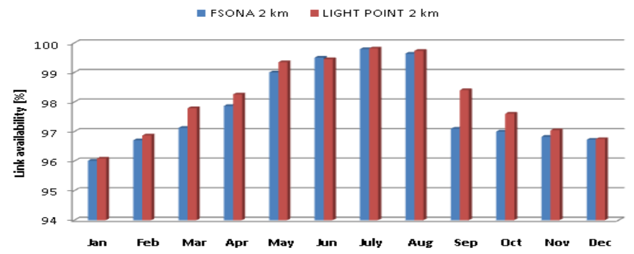

Fig. 5. Link availability, distance 2 km, FSONA, LIGHT POINT (2011).

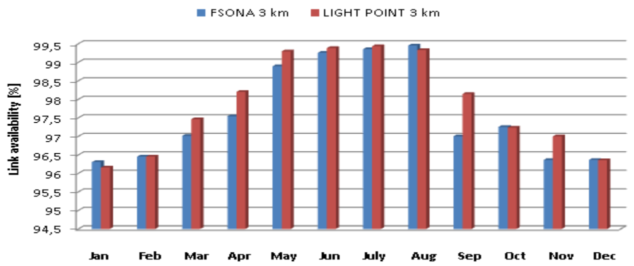

Fig. 6. Link availability, distance 3 km, FSONA, LIGHT POINT (2011).

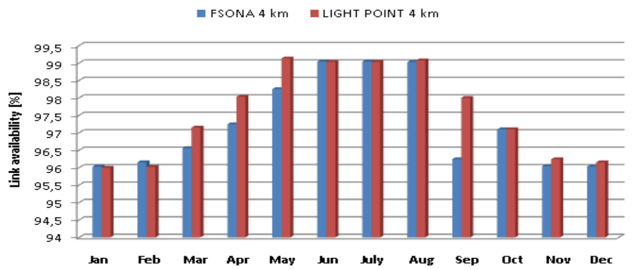

Fig. 7 Link availability, distance 4 km, FSONA, LIGHT POINT (2011)

V. Conclusion

Our simulations and measurements were provided by using "Static and Statistical model" programs. The first part – a fog density value *LWC* – was calculated in "Static model". Input parameters were mainly wavelength λ of a particular FSO, a distance *L* between nodes. Margin and attenuation represented additional calculated parameters. The distance, visibility was changed and investigated starting with 1 and ending by 4 km as shown in the figures above. Link availability is lower during spring and autumn months because foggy and rainy days occur more often. The percentage value of link availability during those months is around 96 % which is under a required FSO standard. In general FSO guarantees the link availability more than 99 % to cover a smooth link operation. On the other hand this technology is still in development process and there are some methods and ambitions how to avoid signal fades. Basically there is no way to avoid such event because when the visibility is too bad, FSO stops functioning. To figure out such situations, producers are already working on hybrid FSO systems, and which will substitute FSO signal when needed (very high fog density during some time, heavy rain, heavy snowing). Such equipment is a combination of FSO laser beam technology and RF signal.

Regarding to the rest months of the year 2011 we can say that results got very standard link availability values (usually more than 99 %). Those results made us sure that FSO link is a suitable technology to use even in our climate conditions.

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Biography

Ján Tóth was born in Trebisov, Slovakia, on Jan. 16, 1988. He received his M.S degree from "Infoelectronics" University of Košice in 2012 at Department of Electronics and Multimedia Telecommunications, Faculty of Electrical Engineering and Informatics. He has started his PhD. studies at Technical university of Košice on September 2012. His main field of study is a reseach of full optical fiber networks and degradation factors

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