Availability and Reliability of FSO Links Estimated from Visibility

M. Tatarko*, Ľ. Ovseník* and J. Turán*

* Technical University of Košice/Department of Electronic and Multimedia Communications, Košice, Slovakia
E-mail: matus.tatarko@tuke.sk, lubos.ovsenik@tuke.sk, jan.turan@tuke.sk

***Abstract*— This paper is focused on estimation availability and reliability of FSO systems. Shortcut FSO means Free Space Optics. It is a system which allows optical transmission between two steady points. We can say that it is a last mile communication system. It is an optical communication system, but the propagation media is air. This solution of last mile does not require expensive optical fiber and establishing of connection is very simple. But there are some drawbacks which have a bad influence of quality of services and availability of the link. Number of phenomena in the atmosphere such as scattering, absorption and turbulence cause a large variation of receiving optical power and laser beam attenuation. The influence of absorption and turbulence can be significantly reduced by an appropriate design of FSO link. But the visibility has the main influence on quality of the optical transmission channel. Thus, in typical continental area where rain, snow or fog occurs is important to know their values. This article gives a description of device for measuring weather conditions and information about estimation of availability and reliability of FSO links in Slovakia.**

I. Introduction

The Free Space Optics (FSO) communication is a growing up technology which offers full duplex and usually protocol independent data transmission between two points. It is line of sight technology but distance between transmitting and receiving points can be from several meters up to a few kilometers. FSO system allows transmit data with high rates which are from hundred of megabits up to a few gigabits. The FSO systems have many advantages. Its installation is very easy and fast, there are no expensive fiber optic cables, no expensive rooftop installations and no spectrum license are required. FSO receiver and transmitter can currently transmit a large amount of data without mutual interferences among other FSO systems. It is difficult to eavesdropping on FSO transmitted data.

The FSO system consists of two receiving and transmitting heads. Each of head can receive and transmit an optical signal and it has own electric/optical and optic/electrical convertor. If we want to establish a connection between FSO stations (heads), we need to find the same directionality and one or both heads must be connected to the general communication network (internet). After successful connection we can disconnect one side from internet and connection between heads will be still maintained. In Figure 1 is hardware diagram of FSO connection.

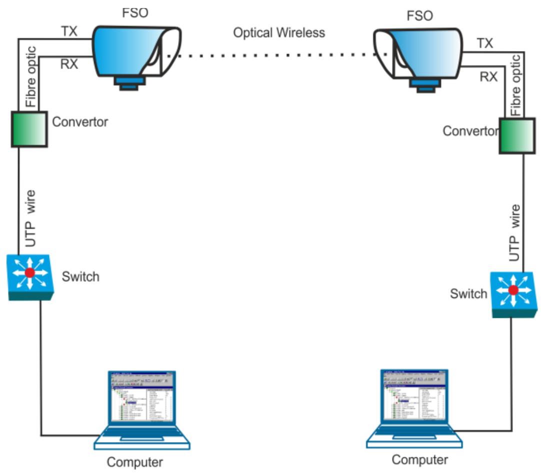

Figure 1. Hardware diagram of FSO system.

Main disadvantage and drawback in FSO connection is a large variation of receiving signal due to atmospheric phenomena. This fact limits the availability and reliability of FSO system for a given transmission range. Thus is very important to measure and know weather conditions such as values of fog, relative humidity and temperature. From these parameters is possible to calculate a value of visibility which unit is kilometer. Free space optical beams are absorbed and scattered by the air molecules as well as by the solid and liquid particles diffused in atmosphere. Absorption of the signal causes a decrease in signal strength. Scattering does not cause a decrease in signal strength, but it send off the signal in different directions [1]. These phenomena occur in foggy days, when relative humidity is high and visibility is low.

In following chapter are mentioned visibility and FSO systems which we use. Third chapter is about description of Fog sensor and mathematical relations which we need to calculating reliability and availability of FSO links. Closing chapter includes experiments and their results.

II. Information about Visibility

Draft information about visibility in Europe we can obtain from weather forecast websites which gives us every day values of visibility. One of these websites is http://www.wunderground.com/global/Region/EU/Visibility.html. But it is only a color map which gives us only informative value of visibility (Figure 2).

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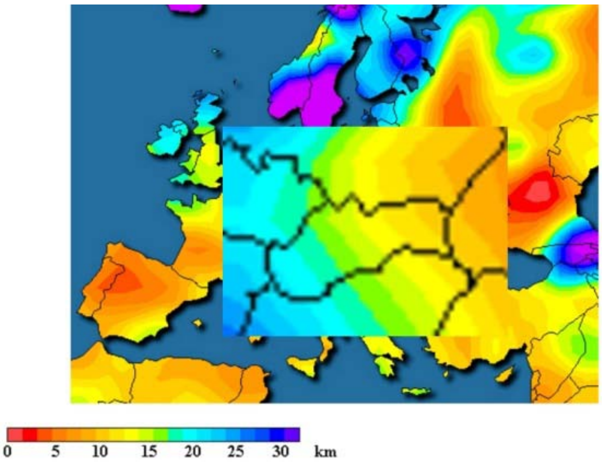

Figure 2. Typical informative color map from webside [9].

In this figure we can see only color scale with some values of visibilities which belongs to a color map. But if we need exact value of visibility in some city, there is a problem. Almost every weather forecast websites does not provide information about visibility, because devices for visibility measuring are expensive. Thus only big cities or airports have this information directly.

As we mentioned above, devices for direct measuring visibility are expensive, so there is need to calculate visibility from another parameter of fog. It is called Liquid Water Content (LWC). It is one of the most important parameters of the fog. LWC describes the mass of water drops in the volume units of the fog. Direct method for measuring LWC consist of extracting a known volume trough a cotton pad or of rotating cups in an impeller apparatus, both to the weighed. Also resistance changes can be measured with a hot wire probe attached to an aircraft flying through the clouds. The value of LWC in the fog varies in a wide range. In a most of the fog attenuation models, it is also required to know the value of LWC [6].

Installation of FSO system requires knowledge of environment where will future FSO system used. At the Technical University in Košice (TUKE) campus we have two FSO systems. Both systems are from American companies, but one is from FSONA and another is from Lighpointe. FSONA system uses 1550 nm wavelength and Lightpointe uses 850 nm wavelengths. One foggy day has different influence on them due to different wavelength. So we need detail information about weather and fog in our campus. We have installed a device for measuring weather parameters such as density of fog, relative humidity and temperature. It is called Fog sensor [7,8].

III. Fog Sensor

It was developed like a simple and low cost device for experimental purposes [7,8]. It measures important parameters for subsequent static and statistical evaluation of the quality of FSO communication environment. Fog has the main influence of transmitting quality, which composes of water vapour or water droplets with 100 nm in diameter. In order to estimate the attenuation due to fog, LWC is measured in unit (g/m^3).

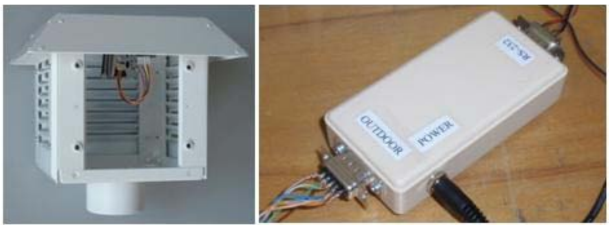

Figure 3. Hardware components of Fog sensor.

In Figure 3 is illustrated two basic parts of fog sensor. Our system consists of an outdoor unit, which performs the measurement and indoor unit which convert data from RS 422 line to RS 232 line. The indoor unit is connected to PC through RS-232 line. The measured data are illustrated in TABLE I. [8].

TABLE I.
Source Data from Fog Sensor

Density (Di)	Temperature	Humidity	Averaging	Relative Time
227	4006	3121	100	0
213	4007	3121	100	1
213	4007	3122	100	2
218	4008	3121	100	3
220	4008	3121	100	4
215	4010	3121	100	5
217	4009	3121	100	6
213	4009	3121	100	7
214	4010	3122	100	8
210	4009	3121	100	9
220	4009	3119	100	10
222	4009	3120	100	11
218	4009	3121	100	12
213	4008	3121	100	13
213	4009	3121	100	14

Measured data can be processed in a PC in several different ways. It can be saved to a file, rendered to chart or stored on the server. In Matlab we can calculate value of LWC from first column of the TABLE I.

A. Data processing in Matlab

For calculation density of fog we use values from first column

$$F = (D_i \cdot \frac{5}{1024} - 0{,}96) . \frac{0{,}5}{2{,}9} \tag{1}$$

where F is a density of fog and D_i is fog sensor output value. If we want to get exact value of LWC, we need to define a constant which helps us to convert value of fog to value of *LWC*. This constant is marked as C and it is from ratio between the average LWC values W_i and the fog sensor output values D_i [7]

$$C = \frac{\sum_{i=1}^{n} W_i}{\sum_{i=1}^{n} D_i} = 0{,}7384 \quad \left[g / m^3 \right] \tag{2}$$

Where n is number of samples during whole fog event. This constant is used to convert the momentary sensor values D_i to momentary *LWC* values [2]

$$LWC = F.C \tag{3}$$

From *LWC* we can calculate the visibility. For the calculation we use the empirical formula for fog visibility as a function of fog density

$$V = d.(LWC)^{-0,65} \quad (4)$$

Where V is a visibility in [km] and parameter d takes on specific values for different fog conditions as shown in TABLE II [4].

TABLE II.
TYPICAL VALUE OF PARAMETER *"d"* FOR DIFFERENT TYPES OF FOG

Type of fog	*d*
Dense haze	0,034
Continental fog (dry and fog)	0,034
Maritime fog (wet and hot)	0,06
Dense haze and selective fog	0,017
Stable and evolving fog	0,024
Advection fog	0,02381

Here are explanations of different fog types which are used in TABLE II.

Dense haze

When visibility is reduced to 5000 meters or less by the presence of dust particles it is called haze. It is not related with cloud forming factors as is the case with fog or mist. When dust or sand particles are blown off and visibility reduces to less than 1000 meters it is referred to as a dust or sand storm, usually not higher than around 45-60 m. In desert areas and with unstable air conditions (steep ELR) fine dust particles can go up to 2500 m or higher and this condition can last for hours and having effects on other continents too.

In Europe it is not uncommon to experience sand dust from the Sahara carried by high altitude winds from the south and eventually raining down well into the northern parts of Europe [3].

Continental fog

Continental fog layers normally restrict visibility to between 4.5 to 8 km and occasionally to less than 1,3 km. It usually dissipates when the atmosphere becomes thermally unstable or wind speeds increase. This occurs with heating advection, or turbulent mixing [3].

Maritime fog

If the initial dew point is less than the coldest water temperature, sea fog formation is unlikely. In pole ward moving air, or in air that has previously traversed a warm ocean current, the dew point is usually higher than the cold water temperature [3].

Stable and evolving fog

Stable air mass with cloud is cover during the day, clear skies at night, light winds and moist air near the surface. These conditions often occur with a stationary, high pressure area [3].

Advection Fog

Advection fog often looks like radiation fog and is also the result of condensation. However, the condensation in this case is caused not by a reduction in surface temperature, but rather by the horizontal movement of warm moist air over a cold surface. This means that advection fog can sometimes be distinguished from radiation fog by its horizontal motion along the ground [5].

Sea fogs are always advection fogs, because the oceans don't radiate heat in the same way as land and so never cool sufficiently to produce radiation fog. Fog forms at sea when warm air associated with a warm current drift over a cold current and condensation takes place. Sometimes such fogs are drawn inland by low pressure, as often occurs on the Pacific coast of North America.

Advection fog may also form when moist maritime, or ocean, air drifts over a cold inland area. This usually happens at night when the temperature of the land drops due to radiational cooling [2,3].

For TUKE campus we use a value for stable and evolving fog. Thus visibility is given by formula

$$V = 0,024(LWC)^{-0,65} \quad (5)$$

B. Data processing of visibility from webside

From websites we can obtain information about visibilities which are given in meters. In the next picture (Figure 4) there is illustrated a way, how we can obtain these values of visibility from different cities in the Slovakia airports.

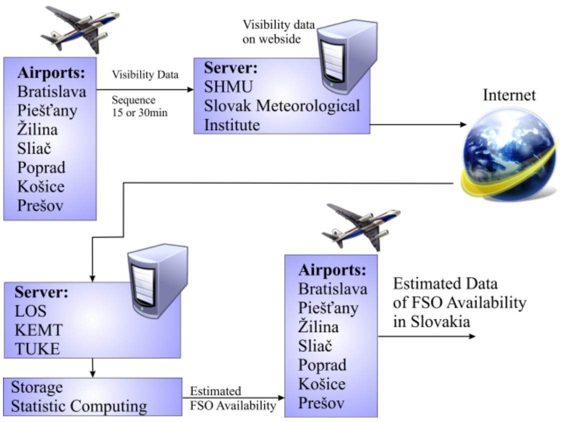

Figure 4. Graphical output of measured data from Matlab.

Slovak Meteorological Institute (SHMU) has several measurement devices deployed in airports. Among big and significant airports we can find small and sports airports too, e.g. in Prešov or Piešťany. This information has SHMU on website. In our optoelectronic systems laboratory (LOS KEMT FEI TUKE: http://los.fei.tuke.sk) we have a program which can download this information to our server every 15 or 30 minutes. This time is depending on refreshing time of source information on SHMU website.

From this information we can calculate FSO availability too.

Attenuation due to fog we calculate with attenuation coefficient

$$\sigma = \frac{3,91}{V}\left(\frac{\lambda}{550nm}\right)^{-Q} \quad (1)$$

Where σ is an attenuation coefficient (km^{-1}), V is a visibility (km), λ is a wavelength (*nm*) and Q is a coefficient depend on visibility. This coefficient Q we can define from two models. First model is Kim model and value of Q is defined [10]

$Q =$	1,6	when	$V > 50$ km
	1,3		6 km $< V >$ 50 km
	0,16 V+0,34		1 km $< V <$ 6 km
	$V - 0{,}5$		0,5 km $< V <$ 1 km
	0		$V <$ 0,5 km

Second model is Kruse model and in this case value of Q is defined [10]

$Q =$	1,6	when	$V > 50$ km
	1,3		6 km $< V >$ 50 km
	-0,585 V1/3		$V <$ 6 km

Power budged model for FSO link is given by relation

$$P_{R_x} = P_{T_x} - \alpha_{sys} - \alpha_{atm} \tag{7}$$

Where α_{atm} is total atmospherical attenuation, α_{sys} is system attenuation and P_{Tx} is mean optical power T_x

$$\alpha_{atm} = \alpha_{part} L - \alpha_{sys} \tag{8}$$

In relation above, L is distance between FSO transmitter and receiver and α_{part} is attenuation due to particles scattering and absorbtion [10].

Power budget for typical FSO links without and with pointing are schown in TABLE III. and TABLE IV. respectively.

TABLE III.
TYPICAL FSO LINK POWER BUDGET WITHOUT POINTING

Parameter	Link distance		Comment
	300m	200m	
LD power	15 dBm 30 mW	15 dBm 30mW	
System loss	-6 dB	-6 dB	Loss Tx/Rx
Geometric loss	-27 dB	-44 dB	Tx- 8mrad pointing error 3mrad
Power on PD	-18 dB	-35 dBm	Clear air
PD sensitivity	-46 dBm 25 nW	-46 dBm 25 nW	Depend on λ and data rate
Clear air link margin	28 dB	11 dB	

TABLE IV.
TYPICAL FSO LINK POWER BUDGET WITH POINTING

Parameter	Link distance		Comment
	300m	200m	
LD power	15 dBm 30 mW	15 dBm 30mW	
System loss	-8 dB	-8 dB	Loss Tx/Rx
Geometric loss	-4 dB	-18 dB	Tx- 8mrad pointing error 3mrad
Power on PD	3 dB	-11 dBm	Clear air
PD sensitivity	-46 dBm 25 nW	-46 dBm 25 nW	Depend on λ and data rate
Clear air link margin	49 dB	35 dB	

In both tables we consider data rate 125/155 Mbit/s.

IV. EXPERIMENTS AND RESULTS

A. Experiments in Matlab

After processing source data in Matlab, we can make two different graphs. First type of graph (Figure 5) is about density of fog, temperature and relative humidity.

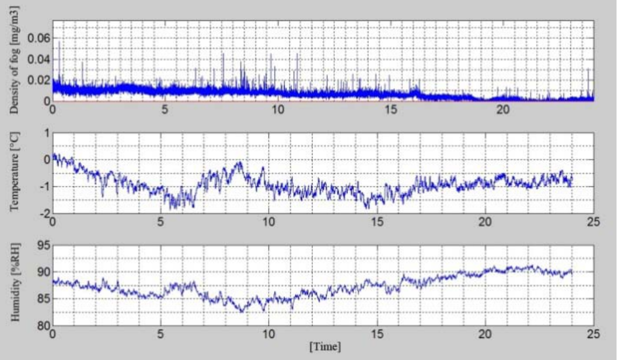

Figure 5. Graphical output of measured data from Matlab.

Second type of graph is shown in Figure 6 and it is a graph of visibility. Source information was from the same day as source information for first graph.

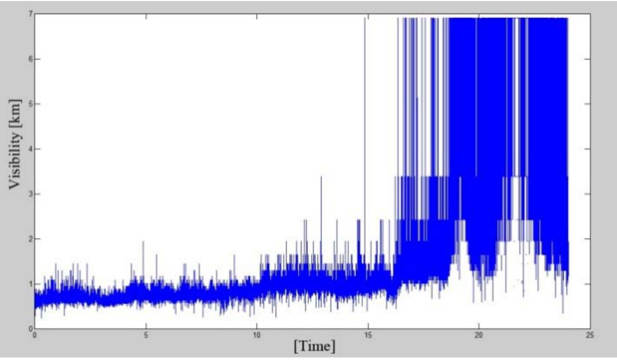

Figure 6. Visibility in Košice on 27th December 2011.

In Figure 7 is a color map of Slovakia from 27th December 2011. It is only informative map too, but we can see, that visibility is in a wide range from 4 km up to 20 km. This is a reason why is necessary to use fog sensor to measure weather parameters. Each place on the map has different conditions for transmitting optical laser beam.

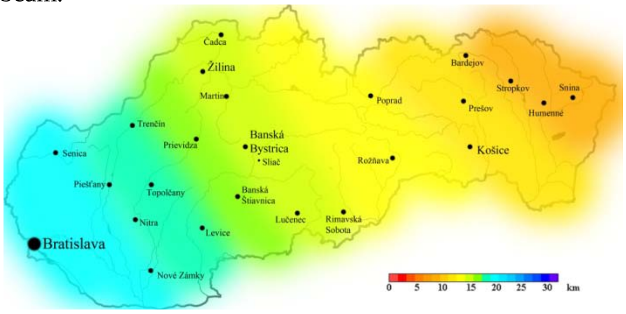

Figure 7. Color map of Slovakia on 27th December 2011.

We can get information about availability and reliability of FSO links from measured data of visibility. In Matlab we can enter the distance or distances between FSO systems. It depends on number of FSO links which are simulated. In our case we have simulated two FSO systems which are working in TUKE campus (Chapter 2).

First FSO link have 451 m (FSONA system) and Second FSO link have 312 m (Lightpointe system). From these distances we can say, that they are available also at minimum visibilities too. But for all values of visibility lower than the threshold value, FSO systems will loss communication of line.

From source data of fog sensor we can calculate an actual visibility in every second per day. In Matlab we can specify the threshold values of distances for both FSO systems. Graph of visibility is created with both thresholds (Figure 8).

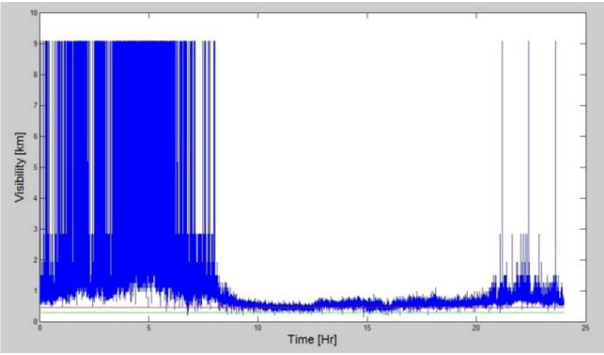

Figure 8. Graph of visibility on 31st December 2011.

In Figure 8 red threshold belongs to FSONA system and green threshold belongs to Lightpointe system. From first look we can see that better availability has Lightpointe system. It is true of course, but we know exactly how many percent per a day was link down. In this case from measured data files we know, that First link was 3004 times per a day down. It is 3,471 % of day. Second link was down only 90 times per a day. It is 0,104 % of day. Measurement was performed on a foggy day 31th October 2011. We can calculate that availability of First FSO link was 96,539 % and 99,896 % for Second FSO link.

Another day is illustrated in Figure 9. This data was measured on 15th November 2011.

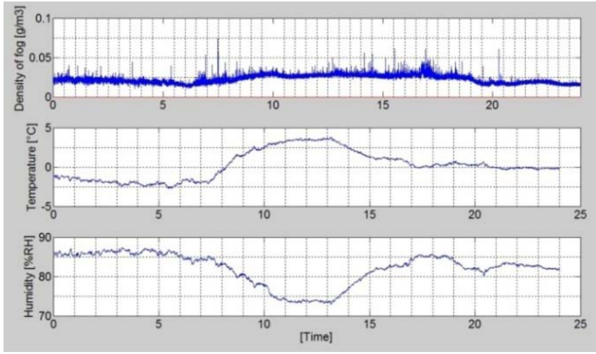

Figure 9. Graphical output from Fog sensor of 15th November 2011.

Graph of visibility is illustrated in Figure 10.

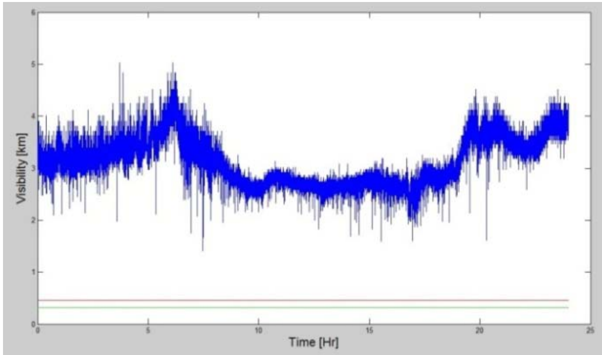

Figure 10. Graph of visibility on 15th November 2011 with thresholds.

From the last graph we can see that all values of visibility are higher than thresholds for both our systems. So availability of both systems was 100 %.

B. FSO system availability estimation with visibility information from website

Visibility information from website is in meter so we must only sort them by distance and then statistically evaluate.

From measured values of visibility in years 2010 and 2011 in Slovak airports, there is a picture of average availability of our experimental FSO links (Figure 11).

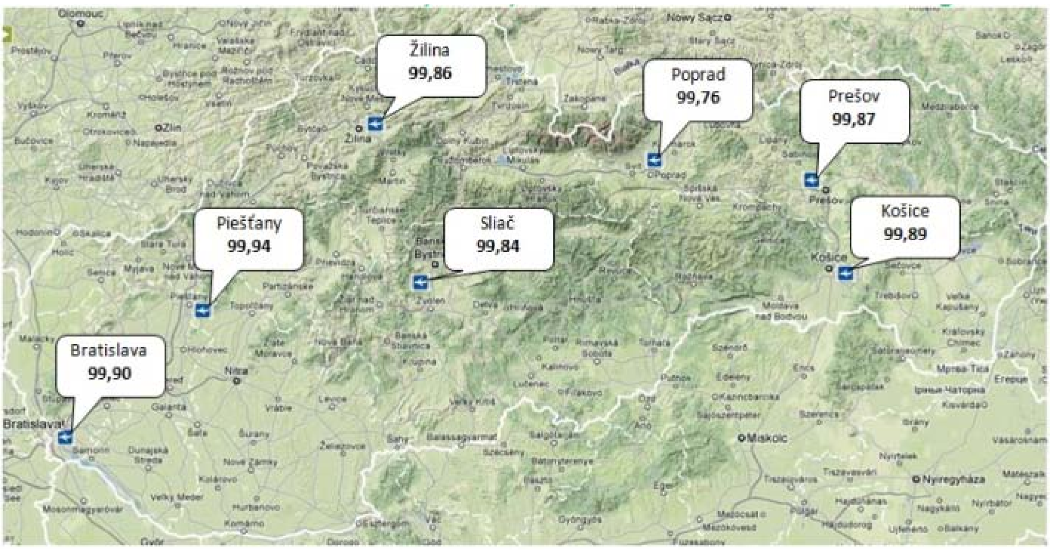

Figure 11. Average availability of FSO links in Slovakia.

In TABLE V. is information of estimated FSO links availability for three selected airports. For this calculation normalized link margin (M_n) is 93 dB/ km. Relation for normalized link margin is given by equation

$$M_n = \frac{M}{L} \qquad (9)$$

Where M is link margin and L is link length.

TABLE V.
ESTIMATED FSO AVAILABILITY FOR SELECTED AIRPORTS

Airports	Estimated FSO range for various availability [m]		
	99,5 %	99,9 %	99,99 %
Piešťany	2200	810	280
Košice	1100	490	270
Poprad	670	360	190

V. CONCLUSIONS

This paper gives us detail information about visibility and methods how to obtain values of it. There are described weather conditions, which have influence on laser beam of the FSO system. Different types of fog, relation between liquid water content and visibility are mentioned too. Our Fog sensor is able to provide this information for us. Fog sensor is installed in TUKE campus of the Technical University in Košice. From information about density of fog, relative humidity, temperature and visibility we can regulate transmitting power of FSO link to reach highest reliability. We exactly know when the signal is decreasing or totally damage due to fog. From website of SHMU we can download values of visibility in Slovak airports. From this data long term availability and reliability of FSO links can be calculated.

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BIOGRAPHIES

Matúš Tatarko (Ing.) received Ing. (MSc.) degree in 2011 at Department of Electronics and Multimedia Telecommunications, Faculty of Electrical Engineering and Informatics of Technical University of Košice. Since September 2011 he has been at University of Technology, Košice as PhD. student. His research interests include free space optics systems and impact weather of them.

Ľuboš Ovseník (doc., Ing., PhD.) received Ing. (MSc.) degree in radioelectronics from the University of Technology, Košice, in 1990. He received PhD. degree in electronics from University of Technology, Košice, Slovakia, in 2002. Since February 1997, he has been at the University of Technology, Košice as Associate Professor for electronics and information technology. His general research interests include optoelectronic, digital signal processing, photonics, fiber optic communications and fiber optic sensors.

Ján TURÁN (Dr.h.c., prof., RNDr., Ing., DrSc.) received Ing. (MSc.) degree in physical engineering with honours from the Czech Technical University, Prague, Czech Republic, in 1974, and RNDr. (MSc.) degree in experimental physics with honours from Charles University, Prague, Czech Republic, in 1980. He received a CSc. (PhD.) and DrSc. degrees in radioelectronics from University of Technology, Košice, Slovakia, in 1983, and 1992, respectively. Since March 1979, he has been at the University of Technology, Košice as Professor for electronics and information technology. His research interests include digital signal processing and fiber optics, communication and sensing.