# Software package for analyze FSO links

M. Tatarko, Ľ. Ovseník and J. Turán

***Abstract*—This paper describes a software package called FSO System Simulator (FSO SystSim), which was designed and implemented at KEMT FEI TUKE (Department of Electronic and Multimedia Communications, Faculty of Electronics and Informatics, Technical University of Košice). Simulation of FSO communication link is very important in designing and understanding the context of such connection depending on various parameters (technically and continually changing atmospheric parameters of the transmission optical channel). FSO System Simulator consists of two basic parts. First part is about Steady model and second part is about Statistical model. Paper briefly describes these models, which are used in programming package and describes experiments carried out by the FSO SystSim.**

***Index Terms*—FSO simulator, modeling, software package**

## I. Introduction

THE free space optical (FSO) systems operate in varying conditions, which parameters cannot be exactly estimated due to changing weather. It is necessary to know the behavior of the FSO transmission lines in all conditions and be able to choose suitable parameters for transmission. It is not the same if the transmission distance is several hundred meters, or several hundred kilometers. Behavior of FSO transmission line in certain areas, where we know the statistical parameters of the atmospheric transmission environment (ATE) for a sufficient long period, describes the so-called statistical model of FSO. Distance, with which will operate optical transmission system, regards to parameters of receivers and transmitters, such as transmitting power, receiver sensitivity, the diameters of transmitting and receiving lenses, laser beam directionality and also distance between the transmitter and receiver is described by steady model of FSO [1,2,6].

There are many types of program packages, which simulate atmospheric conditions and behavior of transmitted optical beams through the atmosphere e.g. LOWTRAN 7, FASCOD, OptiSIM and other. These programs are comprehensive, extensive, expensive but not good for students to understand basic relations and properties. Computer program “FSO System Simulator” was created for study purposes. It contains all the elements and equipments of FSO link. Program is using the input parameters of technical facilities and distance conditions and transmission channel conditions, which calculate the availability of transmission channel, and unavailability of FSO lines in a given environment. Operate this program is simple, intuitive and program is free because it was developed at the Technical University in Košice. It is a good way how to obtain basic knowledge about effects of environment on the FSO.

Before the implementation of effective FSO communication links we need to know their availability and their reliability. Availability and reliability of FSO communication link depends on used systems, but also on atmospheric parameters such as rain, snow or fog [2,8,9]. This is the purpose of our study. Its output is a software FSO SystSim with input parameters (distance, Tx power, Rx sensitivity, Rx lens diameter, directivity of laser, weather conditions etc.), which allow to determine the availability of a communication link. Detailed description of the program is shown in the following sections of this article.

## II. Software Package for the Steady Simulation of FSO Link

From the input technical parameters of devices, distance and conditions of transmission channel, this program calculates availability or unavailability of communication links in a given environment. The program was created in a development environment Microsoft Visual C# 2008 Express Editions [11].

After opening the software package FSO System Simulator, we can see an initial window (Fig. 1).

The whole program consists of three basic parts – Steady and two Statistics (statistical) models. Switching between these models is done by switching the tabs in Windows applications (Fig. 1). This figure shows the steady model.

Window of steady model consists of two parts. On the left side there are options for filling the input data. The right side displays the calculated results. Following figure gives graphical representation of the entered and calculated parameters.

In the program section *Device Properties* the parameters of receiver and transmitter of system are entered manually or there is a possibility to choose systems parameters from the database.

Submitted Aug. 10, 2012, revised Jan. 14, 2013

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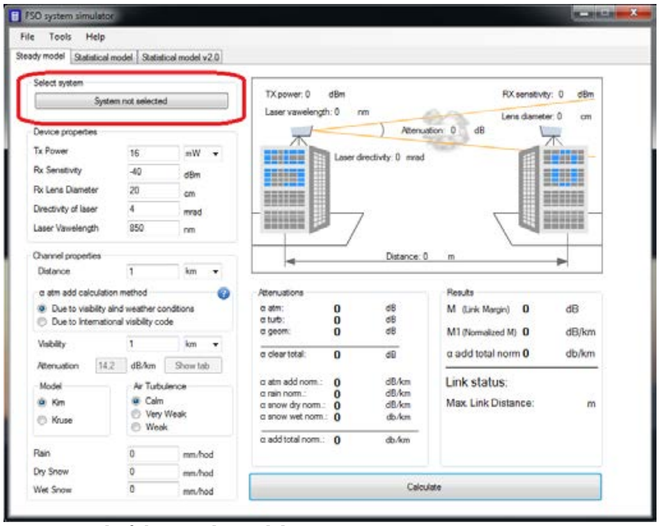

Fig. 1.  Card of the Steady model.

Different parameters of *Device properties* are discussed below:

*TX Power* - is the mean of laser power generates by transmitter. It can be entered in mW or dBm.

*RX Sensitivity* - is the sensitivity of receiver equipment (values from -10 to 70 dBm).

*RX Lens Diameter* - is the diameter of the receiver lens (values from 1 to 100 cm).

*Directivity of laser* - is the laser beam directivity (values from 1 to 60 mrad).

*Laser Wavelength* - is parameter of system wavelength (values from 500 to 1600 nm) [3].

As was noted, each parameter has a limit for entering values. If you enter a value that exceeds the allowed range, the error message is displayed. You have to change the given value and enter new value, which will be in the desired range.

## A. *Description of system database*

A new field was added to the original program and it was called *Selected system* (Fig. 1). This field contains a button that displays the name of the selected system. If there isn´t any selected system, the field contains an inscription *System not selected*. When you click (in this case *System not selected*) on this field, it shows us the database of producers (Fig. 2).

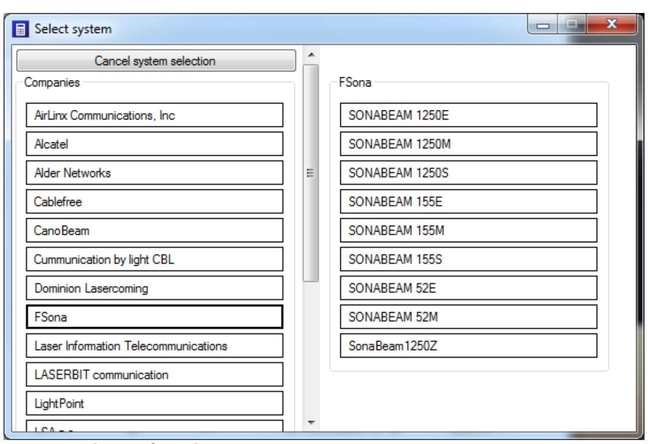


Fig. 2.  Database of producers.

From Fig. 2 we can see that the database of systems consists of two parts. On the left side there is a button to deselect the option and a register of producers. The right side contains the database of the systems of producers. If any producer is selected, field *System of companies selected* displayed *Company not selected*. After selecting a certain producer it will show an overview of products, as is illustrated in Fig.2. When the system is chosen, parameters are copied into above-mentioned field *Device properties*.

To make the selection of systems easier, there is a possibility to display various parameters in the form of help. It allows us to choose a system based on the displayed parameters. The window help appears, when you let the cursor stands for a moment in any part of scheme. The window help contains the information about the system that we need for computing (Fig. 3).

Tx Power: 320 mW
Rx Sensitivity: -15 dBm
Rx Lens Diameter: 10 cm
Directivity of laser: 4 mrad
Laser Vawelength: 1550 nm

Fig. 3.  Detail information about selected system.

After selecting and subsequently clicking on a system button, window for selecting of system will disappear and parameters of selected system can be seen in the *Device properties* and also name of system can be seen in the field *Select system* (Fig. 4).

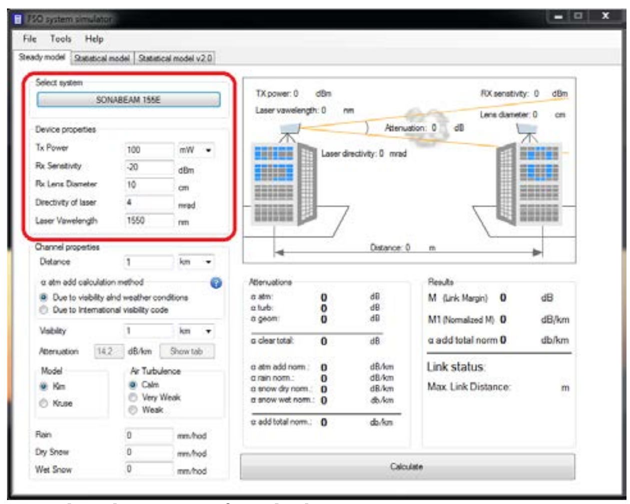

Fig. 4.  Selected parameters from database.

After setting the properties of the channel, it is necessary to press a button *Calculate*. On the basis of the parameters of the system and properties of the transmission channel, the program will calculate availability of connection. Database of FSO systems in this program is suitably designed to allow easy addition of other producers and their systems. Whole database is located in the folder Systems. When we enter to this folder, database of all producers are displayed there (Fig. 5).

New systems are added to individual folders of producers in the form of .txt files with specific parameters. So if we create a new producer by creating new folder with the producer´s name and we want to specify the particular system, we will

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come into this folder and create .txt file as is shown on Fig. 6.

On Fig. 6 we can see nine .txt files of 9 specified systems from FSona Company. Parameters and names of individual systems are added to this .txt files as can be seen from Fig. 7 in the following order: name of system, transmitted power and its unit, *receiver sensitivity*, *receiver lens diameter*, *directionality of laser* and *laser wavelength*.

After filling these parameters into .txt files the database is ready for further input, for example for adding new producers or for changing existing systems parameters, etc.

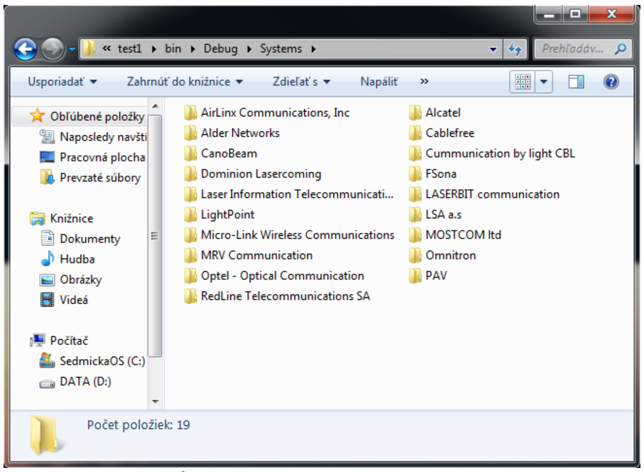


Fig. 5. Entering manufacturers.

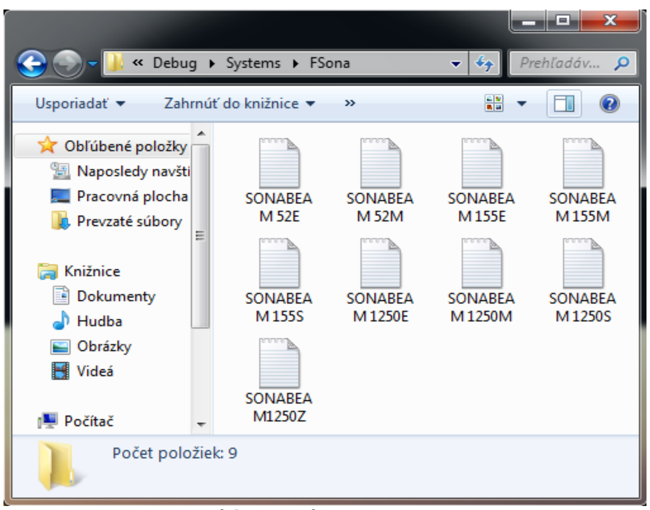


Fig. 6. Entering systems of the manufacturers.

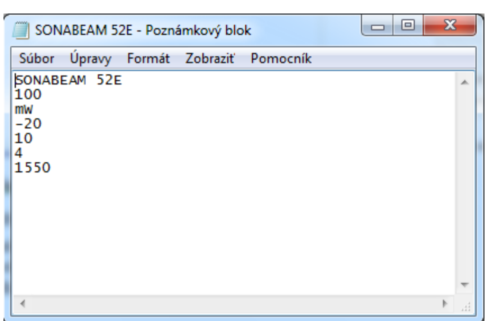


Fig. 7. Text file with input parameters.

## III. Experiments with the Steady Model

Different systems from database can be compared with each other under various weather conditions or we can only verify information provided by producers about their transmission properties.

In the steady model of simulator, you can set weather conditions in part *Channel properties*. The Fig. 8 shows a possibility how to set various weather conditions and how to add the item *α atm add calculation method*. If you choose the option *Due to visibility and weather condition* you can simulate different decreases of signal caused by rain or snow. You can also simulate turbulence by the selection of Kim or Kruse model [15].

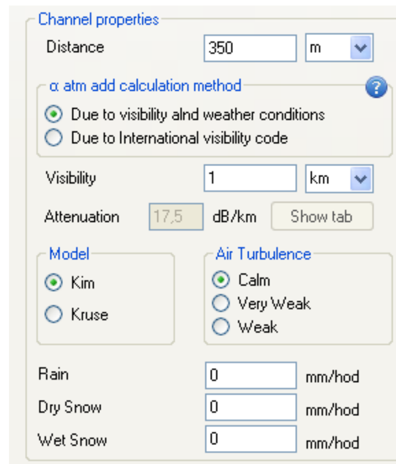


Fig. 8. Entering the atmospheric conditions and visibility due to weather conditions.

If you choose the option *Due to International visibility code* (Fig. 9) you can enter required attenuation to the field *Attenuation* or you can select the option show table. After selection this option a table will be subsequently displayed and we can determine the specific attenuation [dB/km] (Fig. 10). Other fields, except turbulence are hidden. It means that the final attenuation is entered directly to the field attenuation.

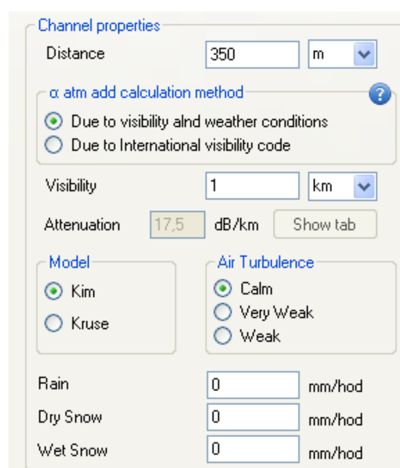


Fig. 9. Entering the atmospheric conditions for Due to visibility and weather conditions.

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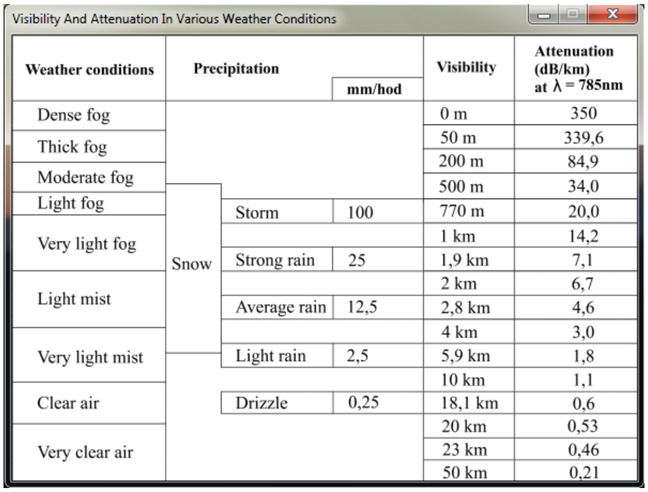
Visibility And Attenuation In Various Weather Conditions

| Weather conditions | Precipitation | | mm/hod | Visibility | Attenuation (dB/km) at λ = 785nm |
|---|---|---|---|---|---|
| Dense fog | | | | 0 m | 350 |
| Thick fog | | | | 50 m | 339,6 |
| | | | | 200 m | 84,9 |
| Moderate fog | | | | 500 m | 34,0 |
| Light fog | Snow | Storm | 100 | 770 m | 20,0 |
| Very light fog | | | | 1 km | 14,2 |
| | | Strong rain | 25 | 1,9 km | 7,1 |
| Light mist | | | | 2 km | 6,7 |
| | | Average rain | 12,5 | 2,8 km | 4,6 |
| Very light mist | | | | 4 km | 3,0 |
| | | Light rain | 2,5 | 5,9 km | 1,8 |
| | | | | 10 km | 1,1 |
| Clear air | | Drizzle | 0,25 | 18,1 km | 0,6 |
| Very clear air | | | | 20 km | 0,53 |
| | | | | 23 km | 0,46 |
| | | | | 50 km | 0,21 |

Fig. 10. Table attenuation of weather conditions.

For testing the reported parameters we have chosen *Due to International visibility code* method. In this method we can exactly specify the required attenuation that is intended by producer. For this test we have chosen MRV Company and their products TereScope 5000 and TereScope 10GE. The producer indicates the availability of links for different attenuation as we can see in TABLE I.

TABLE I
TABLE OF DISTANCES PROVIDED BY THE MANUFACTURERS

| Attenuation | Terescope 5000 Distance (m) | Terescope 10GE Distance (m) |
|---|---|---|
| 3 dB/ km | 5500 m | 1000 m |
| 10 dB/ km | 2700 m | 600 m |
| 30 dB/ km | 1200 m | 300 m |

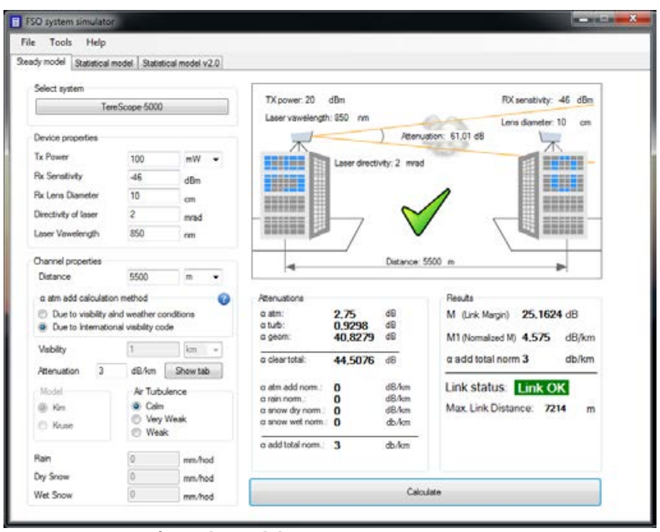


Fig. 11. Output of Steady model.

After selection the system Terescope 5000 and setting the attenuation to 3 dB/ km, which represents the clear atmosphere, simulator calculates the maximum reach of communication link to 7214 m for low turbulence (Fig. 11). With increased turbulence, reach of FSO link is falling down. With *Very Weak* turbulence, reach falls to 6380 m and with *Weak* turbulence reach falls even to 2600 m.

Other calculation for systems Terescope 5000 and Terescope 10GE are shown in TABLE II.

TABLE II
TABLE OF RESULTS FROM THE FSO SIMULATOR

| Attenuation | Terescope 5000 Distance (m) | Terescope 10GE Distance (m) |
|---|---|---|
| 3 dB/ km | 7214 m | 2313 m |
| 10 dB/ km | 3154 m | 1274 m |
| 30 dB/ km | 1339 m | 637 m |

By the comparison of TABLE I and TABLE II we can see, that calculated values are mainly different in system Terescope 10GE, where distances are twice bigger than producer offers. The system Terescope 5000 does not show so big deviations. For the attenuations 10 and 30 dB/km the deviations are 300 m and for the pure atmosphere it is around 1700 m. From the calculations we can say, that the system Terescope 10GE responds better to increase of turbulence than system Terescope 5000 because the increase of turbulence reach caused the decline only a few hundred meters.

### *A. Comparison of different systems among themselves*

Comparison of different systems allows us to understand how deep influence has selected atmospheric conditions to the systems. According to calculations we can determine which product is suitable for the environment and which is not.

For comparison we choose these systems: CableFree Access A1000, Sonabeam 52E and PAV Light Gigabit. We set the same atmospheric conditions for all products, Kim´s model for turbulence *Calm* and visibility 1 km. Distance between transmitter and receiver to 1 km too. Results are shown in Fig. 12., Fig. 13. and Fig. 14.

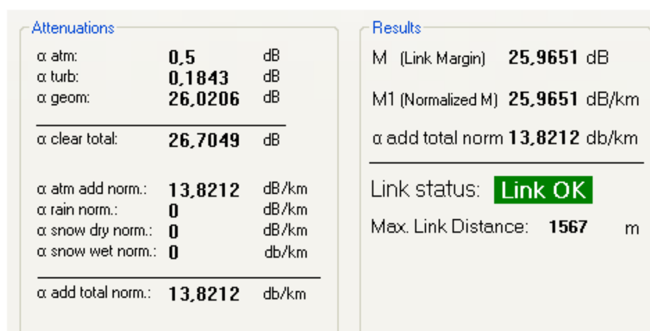


Fig. 12. Output of steady model for PAV Light Gigabit.

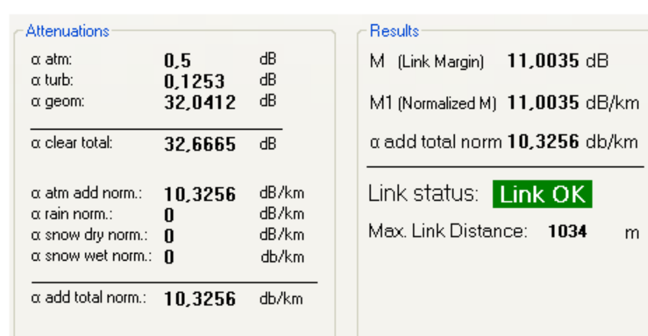


Fig. 13. Output of steady model for Sonabeam 52E.

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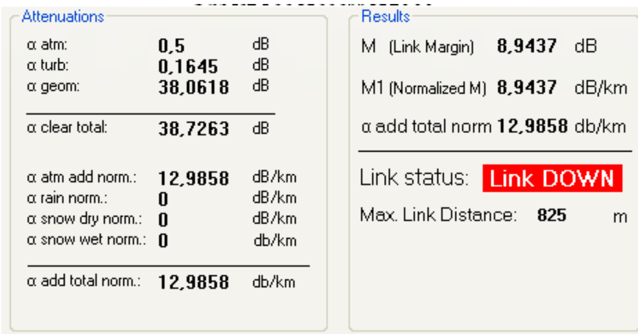


Fig. 14. Output of steady model for CableFree Access A1000.

From obtained data we can say, that first and second system is suitable for the considered environment. System PAV Light Gigabit still has some drawbacks and system Sonabeam 52E is located on the edge of functionality. Third system CableFree Access A1000 is not suitable with these properties for environment.

## IV. Software Package for the Statistic Simulation of the FSO Link

As was mentioned above in chapter two, FSO System Simulator includes two cards that deal with statistical parameters. First card of statistical models is named as *"Statistical model"* and works on the principle collecting data from databases. Collecting data is performed in two ways.

### A. *Statistical model*

The first method uses data which are read from an artificial server that was created through the Wampeserver testing purposes. This database also runs on school website los.fei.tuke.sk. On this server we have created the MySQL database, which consists of two tables whose names are LZIB and LZIB_fade. Table LZIB consists of data downloaded from the websites of airports [3,4]. Downloaded data are about visibilities [m] from these airports.

The second table consists of established values because these values are not freely accessible on the Internet, so they have to be measured. With moving the cursor to set the *Tools* tab and then *Database* Fig. 15 we can see a table of input values, Fig. 16.

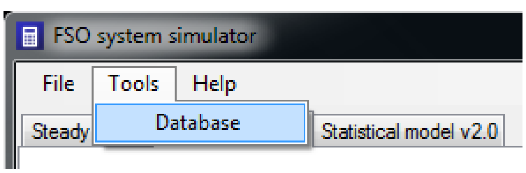


Fig. 15. Procedure to view a table.

As we can see the first tab called *Database settings* contains information about connecting to the server Fig 16.

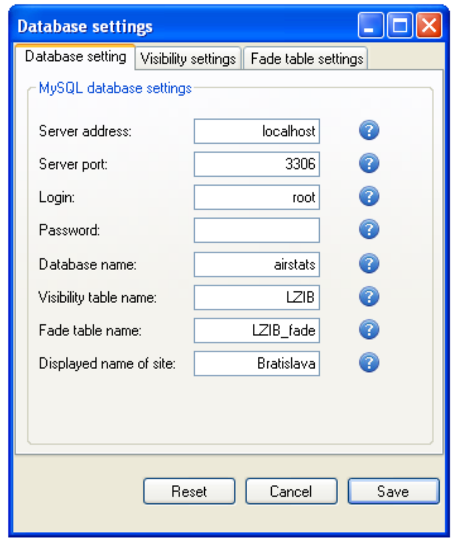


Fig. 16. Assign fields to connect to the database.

Here are described individual items:
*Server address* - the address of server where is given database. In this case it is a virtual server name in the program Wampserver
*Server port*- port number through which is your computer connects to the server. In this case it is the port number of our PCs because the database is running on our PC via the program Wampserver
*Login*- access name to the server
*Password*- password for the server
*Database name*- database name removal, in this case is a database airstats
*Visibility table name*- name of the first table which was downloaded from the websites of airports in this case it is LZIB
*Fade table name*- name of the other creating a table in this case it is LZIB_fade

These settings can be changed for any connection to the server if you know the necessary data.

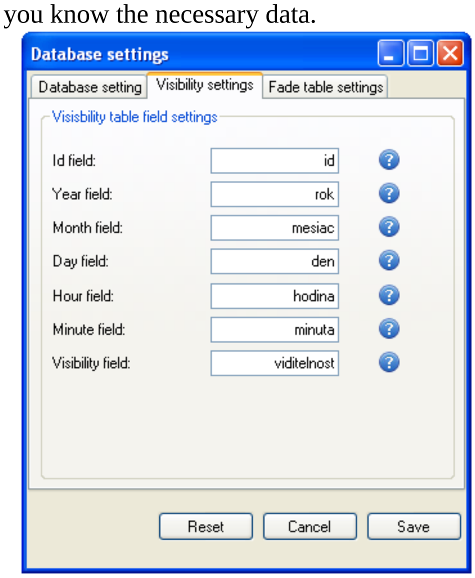


Fig. 17. Assign fields for column headings in table LZIB.

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In the Fig. 17 is illustrated second tab *Visibility settings* represents the columns in the table with titled LZIB. LZIB column in the table are listed under the names we see inscribed in the fields to fill.

Tab in Fig. 18 under the card *Fade table setting* represents the columns in the table title LZIB_fade are listed under the names we see inscribed in the fields to fill.

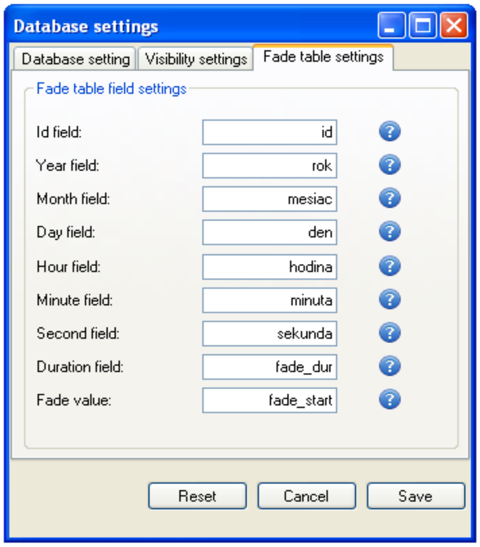


Fig. 18. Assign fields for column headings in table LZIB_fade.

Under the settings in the Fig. 17, Fig. 18 and Fig. 19 there are three buttons.

*Reset*- all user settings are canceled and set to the basic settings

*Cancel*- this button cancel the selection, alternative to this button is red cross into the top of the right corner

*Save*- all user settings are saved

Blue question mark belongs for each input field. After click on it, it provides a help for user.

The second way how to obtain data for calculation in the statistical model is downloading values from tables saved in the .txt file, Fig. 19. Values in row are in this order: id; year; month; day; hour; minute and visibility. Number "id" means the number of seconds from the current day. Every day has 86 400 seconds. The measuring starts with 0 and ends with 86 399.

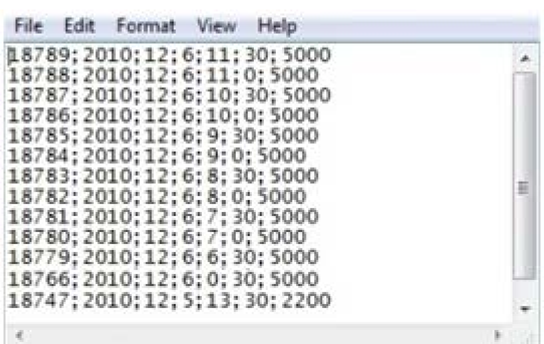
File Edit Format View Help
18789; 2010; 12; 6; 11; 30; 5000
18788; 2010; 12; 6; 11; 0; 5000
18787; 2010; 12; 6; 10; 30; 5000
18786; 2010; 12; 6; 10; 0; 5000
18785; 2010; 12; 6; 9; 30; 5000
18784; 2010; 12; 6; 9; 0; 5000
18783; 2010; 12; 6; 8; 30; 5000
18782; 2010; 12; 6; 8; 0; 5000
18781; 2010; 12; 6; 7; 30; 5000
18780; 2010; 12; 6; 7; 0; 5000
18779; 2010; 12; 6; 6; 30; 5000
18766; 2010; 12; 6; 0; 30; 5000
18747; 2010; 12; 5; 13; 30; 2200

Fig. 19. Saved table in Data Name folder.

The output of the statistical model is shown in Fig. 20 where the first graph shows statistics of attenuation for one day every half hour. The second graph shows statistics of attenuation during one month. Blue curve shows the attenuation value and the red curve is the value of a safety margin. If the blue curve exceeds the red curve, connection will be interrupted. From the first graph we can say, that link was still active and without fades, but on the second graph there are several values which exceed Link margin border.

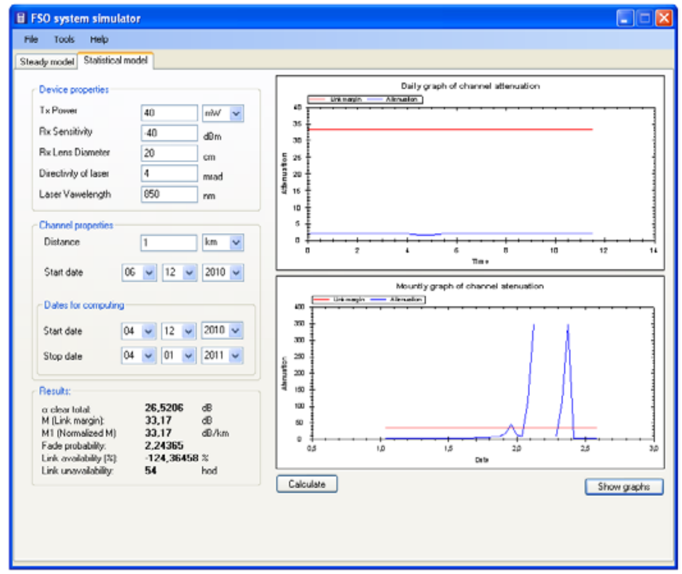


Fig. 20. The output of the statistical model.

The field *RESULTS* contains six values:

*α clear total* - this field displays the attenuation of pure atmosphere calculated from the output values. The value is displayed in dB and it is rounded to four decimal places.

*M (Link margin)* - this field displays the link margin; (output value in dB).

*M1 (Normalized M)* - this field shows the normalized M, it means that M is divided by the total distance.

*Fade probability* – it means the probability of fade and the failure of the connection during the chosen period. This value is rounded to five decimal places.

*Link availability* – displayed value indicated availability of link at percentage for a specified period. This value is rounded to five decimal places.

*Link unavailability* – is value of unavailability of connections for all the time. The value is displayed in seconds if the unavailability of link is less than 900 seconds. If the unavailability of link is greater than 900 seconds but less than 900 minutes the value is displayed in minutes and rounded. If the time stamp value is greater than 900 minutes is displayed in hours.

### B. *Statistical model v. 2.0*

Second card of statistical models is named as "*Statistical model v. 2.0*" (Fig. 21) and works on the principle processing data from Fog sensor. It is a device for measuring density of fog [g/m$^3$], temperature [C°] and relative humidity [%]. From information about density of fog it is able to calculate

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availability of FSO link. Collecting data is performed by the Fog sensor, which measured data and then sending to server every second [13,14].

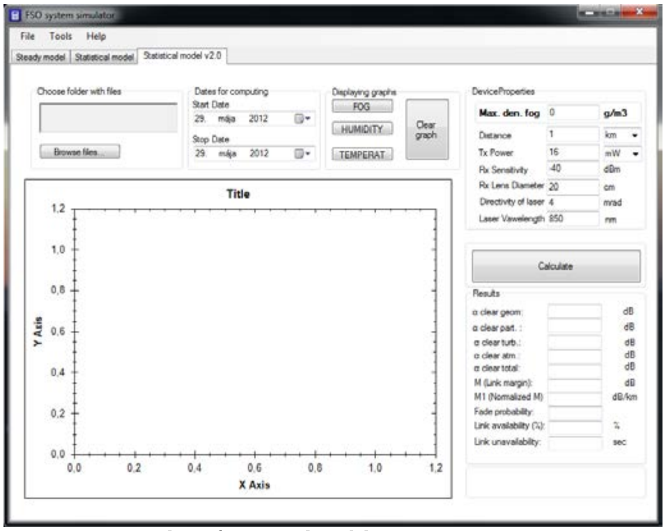


Fig. 21. Main window of Statistical model v. 2.0.

Every day is presented by one .txt file in folder. At the end of the day using .txt file is closed and new .txt file is opened for next day. In every .txt file are five columns. First three columns belong to measured data of density of fog, temperature and relative humidity. Next two columns give us information about average value and sequence number. Every day contains 86 400 values [12].

Before calculation it is necessary make some settings first. You have to do these settings from top left corner to bottom right corner (Fig. 22). At first it is needed to choose folder with files.

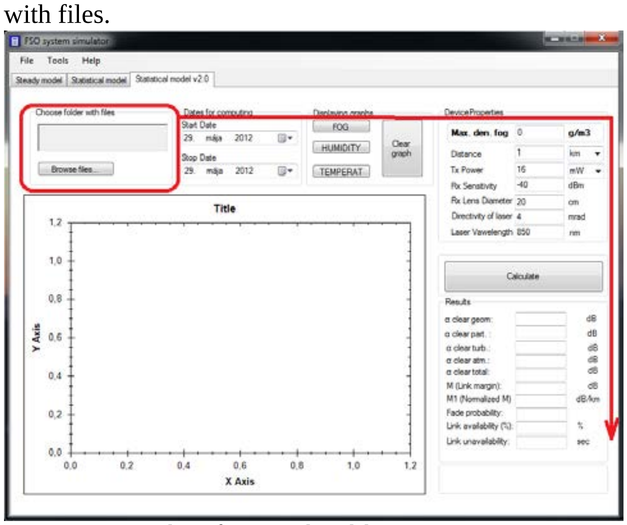


Fig. 22. Main window of Statistical model v. 2.0.

Then you choose actual date from what we want to use data for calculation (Fig. 23). There are two dates for filling, start and stop date. After selection a date is possible to create three types of graph. Graph about fog, humidity and temperature or all three types of graph in one.

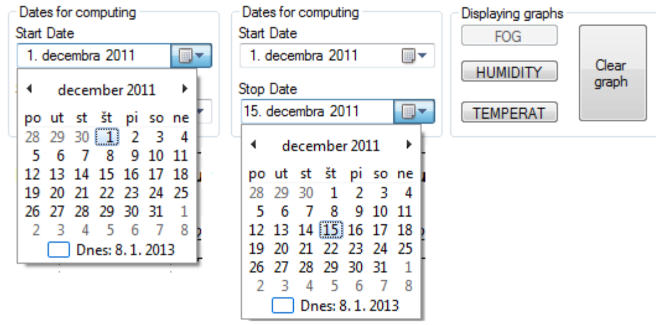


Fig. 23. Choosing dates for calculating from 1.12.2011 to 15.12.2011.

In Fig. 24 is illustrated graph of density of fog calculated from 1-15.12.2011.

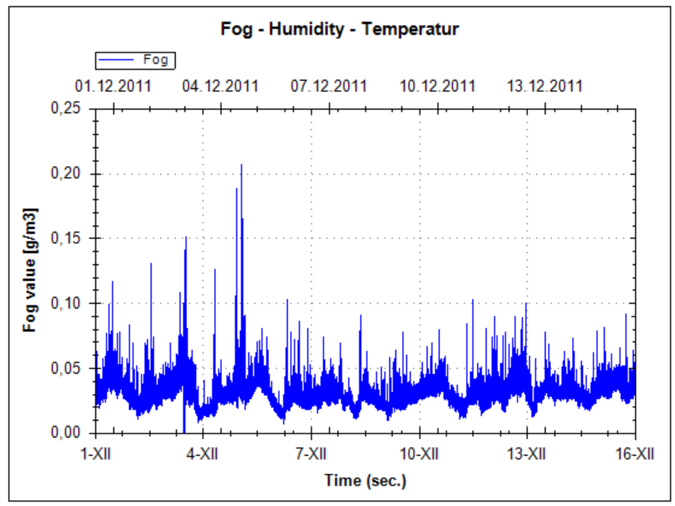


Fig. 24. Graph of fog from 1.12.2011 to 15.12.2011.

Next part of main window is called *Device properties*. There are seven fields for fill (Fig. 25).

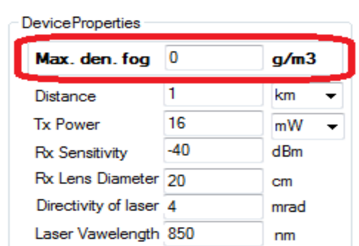


Fig. 25. Device properties.

In this section it is able to fill exact value of device for which you calculate availability of system. *Max. den. fog* is a threshold value for decision if the link is available or not. All values which are higher than threshold value cause decreasing of signal or totally damage of it. Other parameters are described below:

*Distance*- is distance between transmitter and receiver. It can be specified in meter or in kilometer

*Tx Power*- is power of transmitter in dB or mW

*Rx Sensitivity*- is sensitivity of receiver in dBm

*Rx Lens Diameter*- is diameter of receiving lens in cm

*Directivity of laser*- is directivity of laser beam in mrad

*Laser Wavelength*- is wavelength of laser beam in nm

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After filling all parameters it is able to push *Calculate* button and program gets results (Fig. 26).

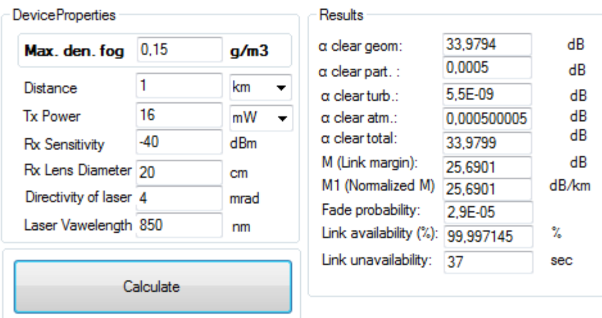



Fig. 26. Results of Statistical model v. 2.0.

Threshold value *Max.den. fog* makes a line in a graph of fog. As we can see in Fig. 27 some measured values of density of fog are higher than threshold. All values which exceed threshold are written in OverFog.txt (Fig.28). Values in row are in this order: measured value of *Max.den.fog*; exact time of fade, count of seconds from current day ("id") and duration of fade.

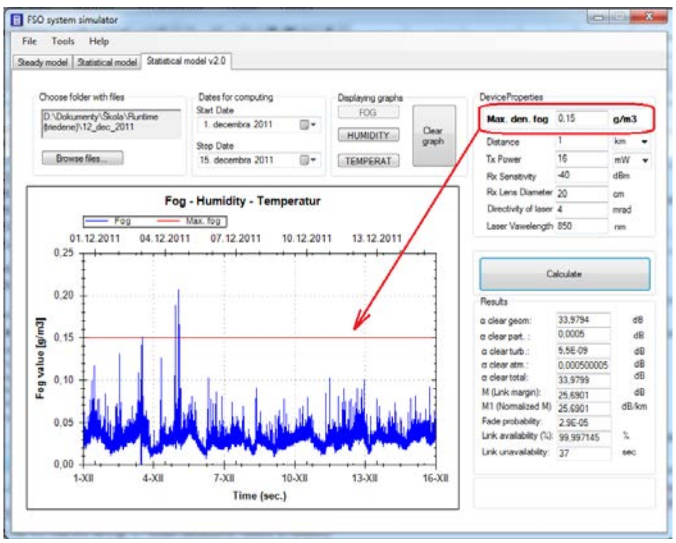
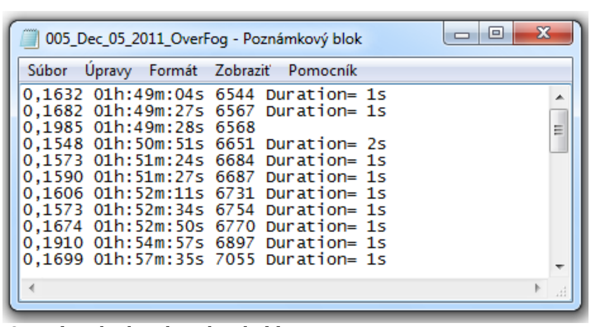



Fig. 27. Graph of fog from 1.12.2011 to 15.12.2011 with threshold.


005_Dec_05_2011_OverFog - Poznámkový blok

Súbor Úpravy Formát Zobraziť Pomocník

```
0,1632 01h:49m:04s 6544 Duration= 1s
0,1682 01h:49m:27s 6567 Duration= 1s
0,1985 01h:49m:28s 6568
0,1548 01h:50m:51s 6651 Duration= 2s
0,1573 01h:51m:24s 6684 Duration= 1s
0,1590 01h:51m:27s 6687 Duration= 1s
0,1606 01h:52m:11s 6731 Duration= 1s
0,1573 01h:52m:34s 6754 Duration= 1s
0,1674 01h:52m:50s 6770 Duration= 1s
0,1910 01h:54m:57s 6897 Duration= 1s
0,1699 01h:57m:35s 7055 Duration= 1s
```

Fig. 28. Values higher than threshold.

In the Fig. 27 you can see a part named as *Results*. All of these parameters are described below:

*α clear geom.*- value of geometrical attenuation under clear atmosphere conditions in [dB]

*α clear part.*- attenuation value of particles under clear atmosphere conditions in [dB]

*α clear turb.*- value of attenuation due to turbulence under clear atmosphere conditions in [dB]

*α clear atm.*- value of atmospheric attenuation in [dB]

*α clear total.*- value of total attenuation under clear atmosphere conditions in [dB]

*M (link margin)*- value of link margin in [dB]

*M1 (normalized M)*- normalized value of link margin to unit length in [dB/km]

*Fade probability*- percentage probability of fade, or loss of signal between transmitter and receiver in [%]

*Link availability*- availability of link in [%]

*Link unavailability*-unavailability of link in [%]

## ACKNOWLEDGMENT

We support research activities in Slovakia / Project is co-financed from EU funds. This paper was developed within the Project "Centrum excelentnosti integrovaného výskumu a využitia progresívnych materiálov a technológií v oblasti automobilovej elektroniky", ITMS 26220120055.

## V. CONCLUSION

Optical wireless communications are evolving technology which rapidly spread from objects in need of reliable backup and high speed transmission (banks and large management companies) through various institutions located in the densely populated and built up areas for internet service provider. Transmission medium for laser beam of FSO systems is air and free environment. It is necessary to know details of each element of transmission channel. For obtaining optimal parameters for setting up the FSO systems is this FSO system simulator the best solution. Simulation of transmission channel of FSO systems is essential tool for designing and experimenting with such devices. FSO system simulator provides many setting for device properties, for weather parameters and making it possible to compare different devices from different manufacturers. Also from measured data about weather conditions allows calculate availability and reliability of FSO link. Statistical evaluation allows us to monitor certain areas during long time and output data gives us an image of potential uses FSO in this area.

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