Free Space Optics Availability and Reliability

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***Abstract*— Free Space Optics technology is a new progressive communication form. The basic FSO link is made of two FSO heads which communicate through a laser beam on a specific wavelength. FSO link requires a direct visibility between its nodes. It is a very efficient form for data transmission for short distance communication links. This paper describes basic FSO features with consideration on negative weather factors which have the negative influence on signal transmission. The unique fog sensor will be presented in this paper. This device gathers some specific data about weather conditions. Measured data is processed mathematically and results can be used in further FSO link evaluation as well as in process of switching FSO link with some form of back up radio link.**

***Keywords*—fog sensor; FSO; availability; web application; fog; reliability**

I. Introduction

The FSO technology (Free Space Optics) has been on a market for a while. This technology provides a full duplex communication between two points (FSO head pair). Nowadays there are a lot of producers who offer various modifications of FSO links [1]. FSO is usually designed to operate from distance of tens of meters to few kilometres (10 km). The latest FSO links are able to satisfy the highest network requirements in term of data bit rate. FSO is widely used in emergency situations when the connection is needed to be set in a short time. The installation of FSO pair is also very convenient and it can be done in few hours. It is important to have a direct visibility for a smooth FSO operation. Therefore any atmospheric pollution, snow, rain, dust and fog have some influence on FSO operation. Before we plan to install FSO in operation in a particular area we need to find out about weather conditions in this area. The fog density has probably the most negative effect on FSO operation. Signal from FSO head is also scattered, absorbed and attenuated when travelling through the free space. We need to monitor atmospheric situation to determinate when FSO signal is not able to go through the obstacles mostly in form of dense fog. In this paper we will present a fog sensor [2]. This device gives us fog density values which are transformed to visibility values. This will give us the information about link availability from a long time interval. This can also serve as the information when FSO system is not able to transmit data because of dense fog and the system is needed to be switched on back up link. This approach is counting on real time data processing from fog sensor for a reliable and smooth operation of the entire FSO link.

II. Web Interface

A. Fog Sensor and FSO Systems

As it has been well known earlier there is no doubt that FSO systems have more advantages than disadvantages. When we talk about short distance applications within campuses, universities, hospitals and relatively small geographical areas FSO links are playing a considerable role. The only question which we have to deal with is if FSO availability and reliability at the certain geographical spot is good enough. There are several approaches how to deal with this question. The main obstacle for FSO is still weather conditions. Namely fog, rain, snow as well as dust in the atmosphere are causing link fades. Our laboratory at the Technical University in Kosice has been dealing with more software based approaches [6] to solve this problem. This software uses data from a fog sensor. This device collects information about fog, humidity and temperature. Based on mathematical calculation forms between fog density (from fog sensor) and visibility there is an evaluation of link availability and reliability of FSO systems. Our ambition nowadays is to take a look at this problem from different point of view. In this paper we will try to introduce web application based approach which in future should process data from fog sensor fully online. This application is working with data stored in a central database. This database is reachable through a web interface [7,8].

B. Fog Sensor

Fog sensor measures raw fog value, humidity and temperature. This data is regularly saved every day in one text file (007_Fog_Humi_Temp_Tue_Jan_08_2013.txt) with the following structure (TABLE I.):

TABLE I. EXAMPLE OF *.TXT FILE GENERATED BY FOG SENSOR

fog(f_i)	temp	humi	avg	time
186	3720	2077	100	33281
185	3720	2078	100	33282
185	3720	2077	100	33283
…	…	…	…	…

A new text file is created everyday as shown in the example above. The name of a file is keeping complex information about the date, a day in a week and an order number under which a particular file was created.

C. Fog Data Conversion

Fog sensor is a device which generates so called raw fog values. These are needed to be recalculated into the values in units [g/m^3] as shown in a following equation (1):

$$F = (f_i \frac{5}{1024} \quad 0.96)\frac{0.5}{2.9}\ , \qquad (1)$$

where f_i is the first column from text file. This value F is needed to be multiplied with the constant $C = 0,7384$ [g/m^3] to get a fog value *LWC* in the exact units and form [M1].

$$LWC = FC \qquad (2)$$

Similarly there are also some specific relations (forms) to convert data for temperature and humidity given by fog sensor to the real temperature and humidity values. These were also applied in a software code [3]. We had a strong motivation to keep data from fog sensor in one central database because of tenability and modularity which database can provide.

D. Database Form

All the text files are saved in one directory which is pre – defined when fog sensor is put in an operation. These files are then processed with a BASH script into one so called merged *.txt file. A merged file is pushed into a MySQL database (Linux CentOS 6.5 platform) in the following step. One can get the following output by using a proper select from a database (Fig. 1).

```
+---------------------+------+-------+------+
| timestamp           | fog  | time  | humi |
+---------------------+------+-------+------+
| 2013-01-08-09:14:41 | 0186 | 33281 | 2077 |
| 2013-01-08-09:14:42 | 0185 | 33282 | 2078 |
| 2013-01-08-09:14:43 | 0185 | 33283 | 2077 |
| 2013-01-08-09:14:44 | 0187 | 33284 | 2078 |
| 2013-01-08-09:14:45 | 0187 | 33285 | 2078 |
| 2013-01-08-09:14:46 | 0187 | 33286 | 2079 |
| 2013-01-08-09:14:47 | 0184 | 33287 | 2078 |
| 2013-01-08-09:14:48 | 0184 | 33288 | 2079 |
| 2013-01-08-09:14:49 | 0185 | 33289 | 2079 |
| 2013-01-08-09:14:50 | 0186 | 33290 | 2079 |
+---------------------+------+-------+------+
```

Fig. 1. Data from fog sensor in MySQL database.

There is a great advantage of using of a MySQL database because applying of mathematical formulas is very convenient. As we can see in (Fig. 2) one can specify a start date with a particular time as well as the end date with a time. Now we are able to see the formation of fog in great details. In (Fig. 2) there are the equations (1, 2) to get so called LWC values – fog [g/m3].

```
+---------------------+------+--------------------+
| timestamp           | fog  | lwc                |
+---------------------+------+--------------------+
| 2013-01-08-09:14:41 | 0186 | 0.0392374461206897 |
| 2013-01-08-09:14:42 | 0185 | 0.0386158135775862 |
| 2013-01-08-09:14:43 | 0185 | 0.0386158135775862 |
| 2013-01-08-09:14:44 | 0187 | 0.0398590786637931 |
| 2013-01-08-09:14:45 | 0187 | 0.0398590786637931 |
| 2013-01-08-09:14:46 | 0187 | 0.0398590786637931 |
| 2013-01-08-09:14:47 | 0184 | 0.0379941810344828 |
| 2013-01-08-09:14:48 | 0184 | 0.0379941810344828 |
| 2013-01-08-09:14:49 | 0185 | 0.0386158135775862 |
| 2013-01-08-09:14:50 | 0186 | 0.0392374461206897 |
+---------------------+------+--------------------+
```

Fig. 2. Calculate LWC values in [g/m3].

Finally when we have *LWC* values satisfactory calculated there is one more step to do. We need to transform from *LWC* fog values to visibility. This information is the main indicator which will help us to decide if the FSO link on the particular distance will be available on not [4,5]. The equation (3) is a relation between *LWC* and visibility *V*:

$$V = d(LWC)^{0.65} \qquad (3)$$

where *d* is a parameter which is defined by various kind of fog from (TABLE II). In our calculations we decided for “*Stable and evolving fog*” which corresponds the best with our geographical conditions and clime.

TABLE II. FOG TYPE “D” FOR VARIOUS KIND OF FOG

Fog type	*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

The following Fig. 3 is referred to the visibility *V* in units [km] calculated from equation (1, 2).

```
+---------------------+------+--------------------+
| timestamp           | fog  | visibility         |
+---------------------+------+--------------------+
| 2013-01-08-09:14:41 | 0186 | 0.196927227084956 |
| 2013-01-08-09:14:42 | 0185 | 0.198982035284643 |
| 2013-01-08-09:14:43 | 0185 | 0.198982035284643 |
| 2013-01-08-09:14:44 | 0187 | 0.194925440989598 |
| 2013-01-08-09:14:45 | 0187 | 0.194925440989598 |
| 2013-01-08-09:14:46 | 0187 | 0.194925440989598 |
| 2013-01-08-09:14:47 | 0184 | 0.201092157985666 |
| 2013-01-08-09:14:48 | 0184 | 0.201092157985666 |
| 2013-01-08-09:14:49 | 0185 | 0.198982035284643 |
| 2013-01-08-09:14:50 | 0186 | 0.196927227084956 |
+---------------------+------+--------------------+
```

Fig. 3. Calculation of visibility V from Equation 1, 2.

E. *Web Acces to Database*

As it has been already mentioned this application also has a web frontend available shown in Fig. 4. This is only a sample image where we defined a start and the end date in January 2013. In this figure we can see plot of LWC as a function of time which is fog in [g/m3].

Fig. 4. Visibility V calculated from Equation 1, 2.

There is a very useful feature implemented in this application. The end user is able to see the results from fog sensor in great details. It is possible to define timestamp boundaries in terms of date in the following format: ‘YYYY-MM-DD HH:MM:SS’. In Fig. 5 is shown a frontend interface in detail.

Fig. 5. FOG sensor interface in detail.

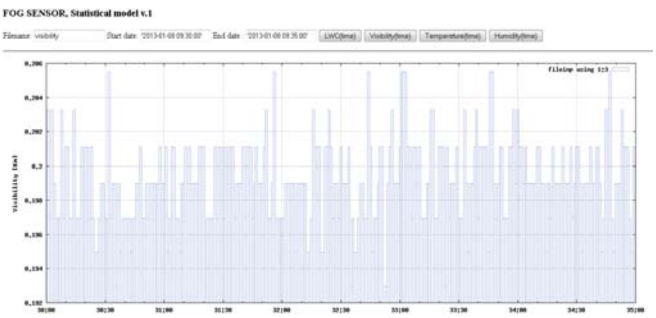

Fig. 6. Example of Visibility.

Fig. 7. Example of Temperature.

It is also possible to graphically display values for Visibility, Temperature and Humidity as functions of time in figures (Fig. 6), (Fig. 7), (Fig. 8).

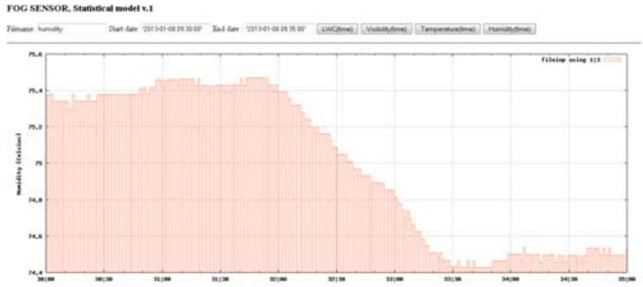

Fig. 8. Example of Humidity.

III. EXPERIMENTS

We are investigating a model situation which was in fact tested at our department for one week. The distance between FSO pair was approximately 200 m. We decided to demonstrate some examples. The distance between two FSO heads (transmitter and receiver) is set to 200 m. We can find some reference values for LWC and Visibility in table (TABLE III.) and (Fig. 9). It means that if raw fog value will exceed value of 0,04 which corresponds with LWC value 184 then we can consider that link is not available. Then we can calculate the probability of link availability or unavailability during a specific time period. By using our web frontend interface there is an option to define this LWC value for a particular visibility which we want to investigate. As the result of this calculation we will get a percentage availability of FSO link equation (4), where $T_{inactive}$ is time [s] when there was a fade. T_{total} is a total time interval we are investigating.

$$P_{available} = 1 - \frac{T_{inactive}}{T_{total}} 100\% \tag{4}$$

TABLE III. CALCULATED FOG, LWC AND VISIBILITY VALUES

Fog(raw)	LWC	Visibility [km]
134	0,006912554	0,608760125
136	0,008155819	0,546710376
140	0,010642349	0,459871891
144	0,013128879	0,401202163
148	0,015615409	0,358427684
155	0,019966837	0,305499294
166	0,026804795	0,252274364
175	0,032399488	0,223029055
180	0,035507651	0,210136735
182	0,036750916	0,205488221
184	0,037994181	0,201092158

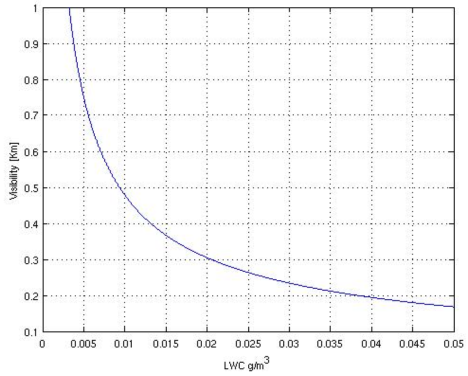

Fig. 9. Visibility [km] as a function of LWC [g/m3].

The year March 2013 was taken for our experiments and demonstrations. As it was already mentioned our web frontend provides us high scalability which will be seen in the following figures. Figure (Fig. 10) is referring to the first day in March 2013. We can see from (Fig. 10) that Fog (LWC) is most remarkable during morning hours (red rectangle).

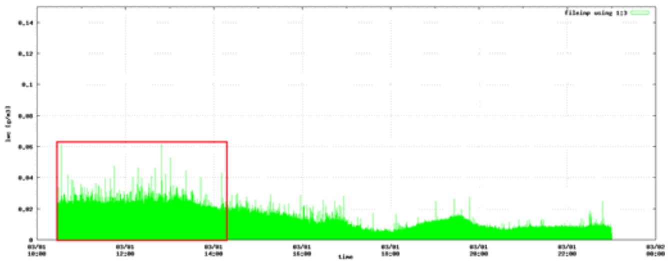

Fig. 10. LWC (time) 1st March 2013, link availability 99,95790407 %.

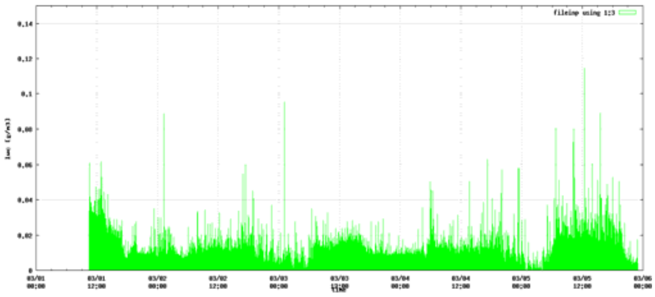

Fig. 11. LWC (time) '2013-03-01 02:00:00' - '2013-03-05 23:00:00', link availability 99,9818267 %.

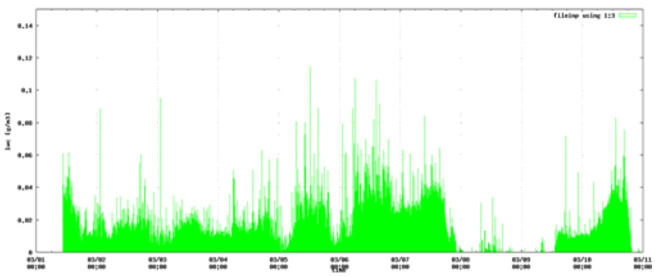

Fig. 12. LWC (time) '2013-03-01 02:00:00' - '2013-03-10 23:00:00', link availability 99,96681299 %.

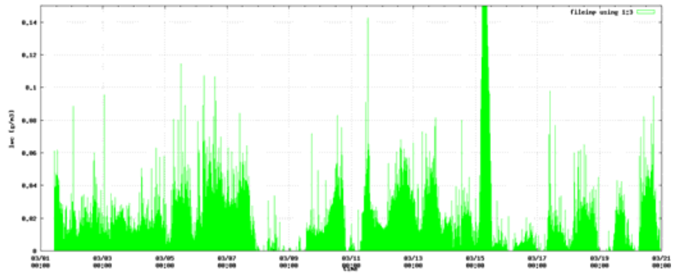

Fig. 13. LWC (time) '2013-03-01 02:00:00' - '2013-03-20 23:00:00', link availability 98,31737998 %.

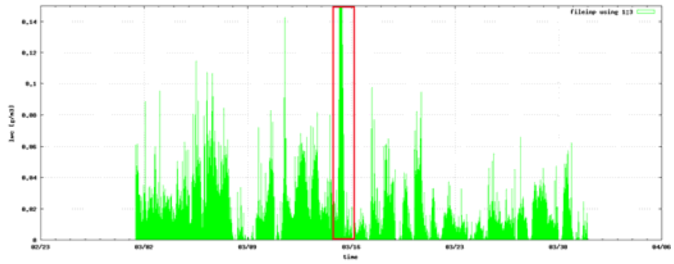

Fig. 14. LWC (time) '2013-03-01 02:00:00'- '2013-03-31 23:00:00', link availability 98,922906 %.

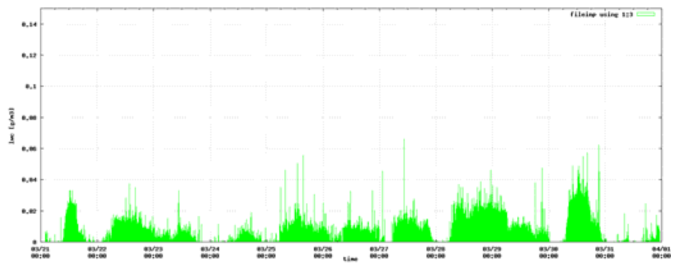

Fig. 15. LWC (time), '2013-03-21 02:00:00' - '2013-03-31 23:00:00' link availability 99,99723257 %.

On the left side we can notice gradually increasing numbers of days processed by our frontend web application. As it has been already mentioned we set LWC limit to 0,04. One can see periodically fluctuating LWC values in time as fog was evaluating and disappearing during particular days. There was link availability calculated for each figure shown in (TABLE IV.).

TABLE IV. LINK AVAILABILITY FOR PARTICULAR TIME PERIOD

Figure Number	Start Date	End Date	Avail. [%]
10.	'2013-03-01 02:00:00'	'2013-03-01 23:00:00'	99,95790407
11.	'2013-03-01 02:00:00'	'2013-03-05 23:00:00'	99,9818267
12.	'2013-03-01 02:00:00'	'2013-03-10 23:00:00'	99,96681299
13.	'2013-03-01 02:00:00'	'2013-03-20 23:00:00'	98,31737998
14.	'2013-03-01 02:00:00'	'2013-03-31 23:00:00'	98,922906
15.	'2013-03-21 02:00:00'	'2013-03-31 23:00:00'	99,99723257

There is the worst value of link availability (98,31737998 %) achieved for first 20 days in March 2013 as we can see from (TABLE IV.). However when we take a look at the figures (Fig. 13) or (Fig. 14) we can assume that this probability was strongly influenced by one foggy day within March 15th. After some deeper investigation it is possible to directly identify a critical time which is the cause of this significant fog (LWC) peak. We can see some detailed view of March 15th in (Fig. 16) when fog values highly crossed our predefined value of LWC = 0,04.

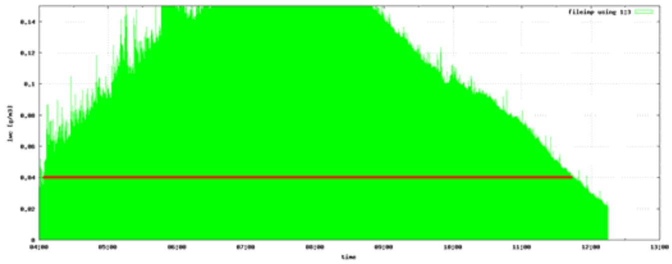

Fig. 16. Detailed LWC (time) March 15th from 04:00 am till 12:15.

IV. Conclusion

Web frontend application is a complex tool which is requesting and processing data stored in database. Based on the end user definition of Start and End Date is a specific format the application is providing *.txt, *.png outputs as well as information about FSO link availability. This application can be used as a tool which statistically evaluates reliability and availability of FSO systems. Moreover after some additional improvements it could be used in process of switching FSO link with secondary back up link in form of 60 GHz radio link or another form of back up link.

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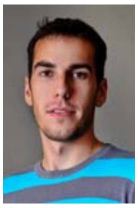
Biography

Ján Tóth (Ing.) 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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