Switching of Hybrid FSO/RF Link Using Fog Sensor

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***Abstract*—The paper describe a new method for switching in hybrid Free Space Optics/ Radio Frequency (FSO/RF) link based on use of simple Fog Sensor. Fog Sensor operation principle is described with experimental method of how to do switching between FSO and RF link in hybrid transmission system. Results of experimental verification of the proposed switching method are discussed.**

Keywords—fog sensor; free space optics; hybrid link; radio frequency link; switching

I. Introduction

FSO (Free Space Optics) are modern communication systems based on wireless transport of optical signal. FSO offers full duplex and usually protocol independent data transmission between two static points [1,2]. The FSO systems use infrared beams to transmit data via atmosphere. They are three atmospheric windows (850, 1300 and 1550 nm) where the attenuation of atmosphere is minimal [3,4,5]. Atmospheric transmission channel is unstable and unpredictable, so monitoring of environment is needed. Atmosphere phenomena decrease the intensity of optical beam in different ways such as absorption, scattering and scintillation. The major negative influence on optical signal is caused by small particles of water (fog); dust and smog in the air.

In RF communication link, data is transmitted through the air too, but by digital radio signals at a given frequency, typically in the 9 kHz to 300 GHz range [3]. In combination with FSO systems, RF systems use 60 GHz antennas. Beam width for antenna´s diameter 30,48 cm is 4,7°. This 60 GHz antenna allows using high speed bit rate and connection has high resistance to interference, high security and multiple use of frequency [4]. Factors which have negative effects on FSO are negligible for RF systems. This is the main reason, why are RF links used as backup links for FSO links. For FSO systems, fog and with fog joint visibility is critical factor for its availability and reliability. On the other hands, RF links show almost negligible fog attenuation, while they usually suffer from other precipitation types like rain or wet snow. Combining these two technologies to hybrid FSO/RF link increase overall availability, guaranteeing quality of service and broadband connectivity regardless of atmospheric conditions [6]. The RF link should be available whenever the FSO link is not i.e. it should not be influenced by fog or other weather effects reducing visibility.

In the second chapter, known switching methods are described. Third chapter describes Fog Sensor. Last chapter describes experimental method how to do switching between FSO and RF link using information about visibility obtained from Fog Sensor data.

II. Switching in Hybrid FSO/RF Systems

Hybrid FSO/RF link is considered as alternative and cost competitive solution for high-speed, point-to-point wireless communication. They combine the advantages of both links. FSO links provide gigabit data rates and low system complexity, but there are data loss mainly due to fog and scintillation. RF links have lower data rates compared to the FSO links, but their main advantage is its independence from the weather.

A. Hard Switching

Switching between the FSO and the RF link can be carried out with a hard switching based on feedback from the receiver. Data transfer is selected either FSO or RF link so that if conditions allow reliable communication channel high-speed FSO link is chosen, otherwise, all data is sent over RF link. This method is not effective, because it uses only a single medium at the same time (Fig. 1).

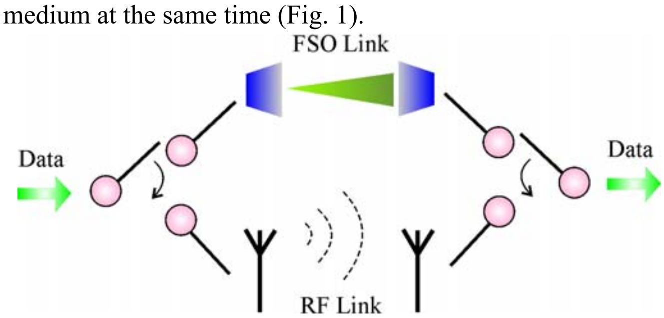

Fig. 1. Schema of the hard switching.

To overcome the disadvantages of hard switching is to coordinate data transfer in both links using channel coding. The data is encoded with LDPC code with a part of codeword divided into FSO and RF links and the speed is adjusted based on current channel conditions.

B. *Soft Switching*

Practical soft switching of hybrid FSO/RF system is designed and implemented using short length Raptor codes. The advantage of using this code is that the encoder does not require channel information and a code automatically adjust the speed of the FSO and RF unit according to the weather conditions. Raptor code encoded packets are transmitted simultaneously over both links and adapt to the conditions of the two links with very limited feedback. Raptor code is designed to be able to transfer data using FSO link with higher rates than in the back-up RF link.

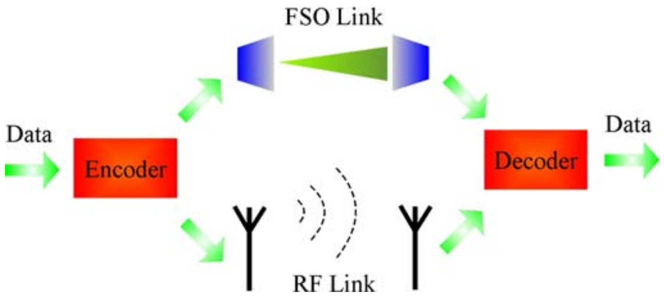

Fig. 2. Schema of the soft switching.

More information about hard and soft switching; configuration commands and devices for switching are describes in our other articles [7,8].

III. Fog Sensor

The most significant negative factors influencing the signal quality of optical wireless communication system are various atmospheric phenomena. They cause a significant reduction in the reliability and availability of the FSO systems. The size of the effects depends on the transmission range of the system and on the characteristic values of the atmosphere, respectively to the weather conditions including factors such as relative humidity, temperature and density of the fog. From measurements of the fog density it is possible to calculate the visibility [km].

From the physical atmospheric properties is able to see that the molecules of air, liquid and solid particles suspended in the atmosphere causes the partial dispersion and absorption of the optical signal received by the lens. During foggy days when the relative humidity is high and the visibility is low, there is a decrease in the signal strength and the leakage outside the trajectory of an ideal direction. To determine the attenuation caused by fog is necessary to measure the Liquid Water Content (LWC) [9].

Devices for the direct measurement of visibility are expensive. Therefore the low cost device (Fog Sensor) for experimental purposes was developed (Fig. 3). It can measure the quantity of LWC in the air [9,10]. It can also measure temperature and relative humidity of the environment.

Fig. 3. Fog sensor device.

Sensor for measuring density of fog is stored in a box to protect it from direct sunlight and rain, but allows free movement of particles to the sensor. Sensor sends and receives infrared pulses which are scattered on water and dust particles (Fig. 4).

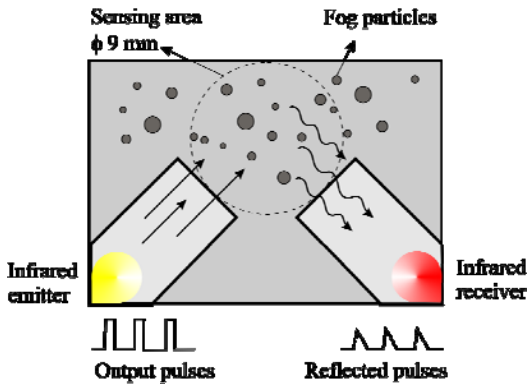

Fig. 4. Principle of measuring density of fog.

Measured data from Fog sensor is stored in .txt file in five columns (TABLE I.). New .txt file is created every day. Time is in range of 0 to 86 399. It means 24 hours in seconds, starts with zero.

TABLE I. Measured data before processing

Density of Fog (D_i)	Temperature	Humidity	Averaging	Time
227	4006	3121	100	0
213	4007	3121	100	1
213	4007	3121	100	2

For calculation values of fog density we use a source data from first column to equation (1).

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

where F is a density of fog and D_i is fog sensor output value. If we want to get exact value of liquid water content, 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 liquid water content values W_i and the fog sensor output values D_i.

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

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]:

$$LWC = F \cdot C \qquad (3)$$

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

$$V = 2 \cdot C \cdot \rho \cdot LWC^{-1}\ , \qquad (4)$$

where V is the visibility [m], ρ the droplet radius in microns and C a constant. The average water content in fog of various types may be computed from measured values of visibility and drop size with C= 2,6. Cloud, fog and mist droplets are very small. Their mean diameter is typically 10-15 micron. [11].

IV. Switching in Hybrid FSO/RF Systems

Our proposal of switching in hybrid FSO/RF systems is primarily based on information about weather conditions obtained from Fog Sensor. We need to set the threshold value for switching. The threshold value is given in [g/m^3]. Using formula (4) we are able to convert visibility to liquid water content. The threshold value is further marked as k. TABLE II. obtains values of converted data in range of visibility from 100 to 1000 m.

TABLE II. VISIBILITY AND PARAMETER k

Visibility [m]	Parameter k
100	0,6760
150	0,4507
200	0,3380
250	0,2704
300	0,2253
350	0,1931
400	0,1690
450	0,1502
500	0,1352
550	0,1229
600	0,1127
650	0,1040
700	0,0966
750	0,0901
800	0,0845
100	0,6760
850	0,0795
900	0,0751
950	0,0712
1000	0,0676

If we have these convert values we can start the Fog sensor application. We need to choose .txt file with measured data and enter the threshold value which corresponds with visibility, Fig 5.

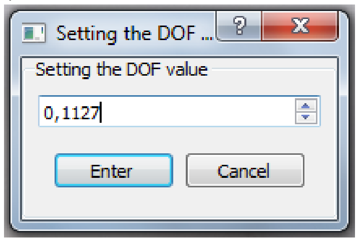

Fig. 5. Parameter k setting window.

The parameter k is constantly compared with measured fog data. The result is pair of graphs which are complementary. It means that if the weather conditions were favourable the FSO system ran and if the weather conditions were unfavourable the RF system ran. For illustration were chosen two distances FSO/RF systems in the same day, 5th May 2014.

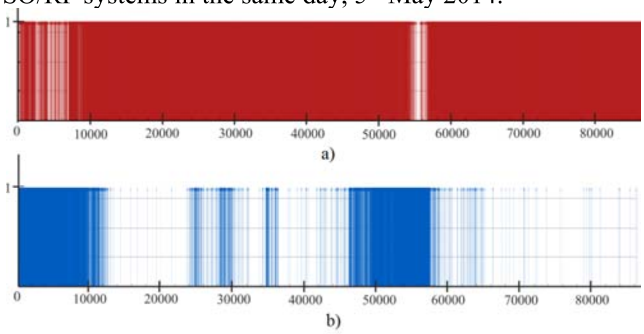

Fig. 6. Activity diagram of Hybrid FSO/RF system, 5th May 2014; a) FSO activity, b) RF activity for 150 m.

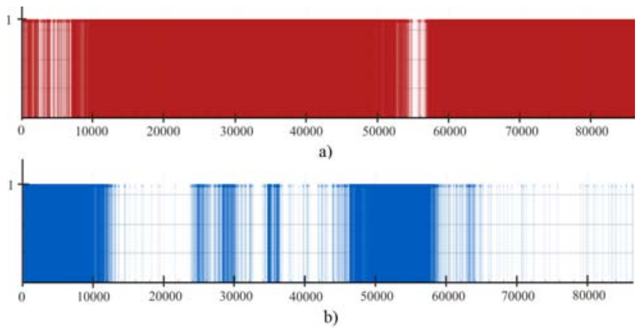

Fig. 7. Activity diagram of Hybrid FSO/RF system, 5th May 2014; a) FSO activity, b) RF activity for 500 m.

Every day has 86400 samples, because every second one measure of atmosphere is done; information about fog, relative humidity and temperature. Software application allows loading and evaluating the stored data from older days too.

If we need depth analysis of measured data, we can use Statistical version of FSO System Simulator. It allows making .txt files with all exceeded values which are higher than threshold in exact time [12]. FSO System Simulator also allows creating graphs of relative humidity and temperature in selected time period.

V. Conclusion

Switching in hybrid FSO/RF systems is very critical. It is important to find the right threshold or time to achieve the maximum availability of this system. Two types of switching are known; soft switching and hard switching. We use Fog Sensor for measuring information about weather condition (fog density) to switch in hybrid FSO/RF system. Advantage of this type switching in hybrid FSO/RF system is in using known information from Fog sensor in different ways. We do not need another device for evaluating atmosphere conditions or device for monitoring traffic. The entire decision logic is based on the fog sensor.

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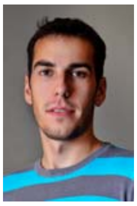
Biographies



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