THE EFFECT OF WEATHER ON QUALITY OF EXPERIENCE IN OPTICAL WIRELESS COMMUNICATION SYSTEM (selected from CEMA'17 Conference)

Rasa Bruzgiene*, Lina Narbutaite*, Erich Leitgeb**, Pirmin Pezzei**, Thomas Plank**

* Kaunas University of Technology,
K. Donelaičio g. 73, 44249, Kaunas, Lithunia.
** Graz University of Technology
Rechbauerstraße 12, 8010 Graz, Austria
Email: rasa.bruzgiene@ktu.lt

Abstract

Optical Wireless communication systems are a good competitor to other wireless communication technologies in relation of its capacity to deliver high-speed broadband traffic. The way optical wireless transceivers operate is more or less the same as fiber optics ones; however, since laser signals are transferred through the atmosphere, the path loss between the transmitter and the receiver is getting raised due to various external factors (conditions) that appear on weather. The characteristics of optical wireless systems and its changes in the face of different weather conditions strongly affect the parameters of Quality of Service. Also, this influence provides the possibility to quantify the significance of the service disruption impact to the metrics of Quality of Experience. Due to this, this paper gives a new approach to the relation of the characteristics of optical wireless communication system, known as Free Space Optics, affected during the weather-based disruptions with the parameters of Quality of Service. Furthermore, this relation is used in estimation of Quality of Experience metrics.

1. INTRODUCTION

Optical Wireless (OW) systems are the good example of the integration between optical and wireless radio communications, where the light of different types is caring the main signal for data transmission over the atmospheric channel. The basic Optical Wireless system consists of three main parts (Fig. 1) - source system (optical transmitter, a modulator and an irradiation device – a telescope or a lens), channel for signal transmission and receiver system (a detector, a decoder, and a telescope or a lens).

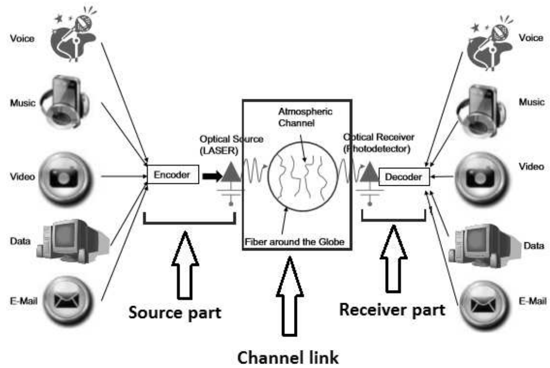

Figure 1. Structure of Optical Wireless communication system [modified from [1]].

In OW system, the information from the optical transmitter is modulated on a collimated beam of light, which is projected through free air channel onto the receiver side [1]. The channel for signal transmission is a free space (air). Since the medium for signal carrier is a light, such system operating frequencies are very high and range from 300 GHz to 300 PHz. It includes infrared (750 nm – 1mm), visible (390-750 nm) and ultraviolet bands (200-280 nm) [2]. Due to this, Optical Wireless communication can be classified into Free Space Optics (FSO), Visible Light Communication (VLC) and Ultraviolet Communication (UVC). FSO, known as terrestrial point-to-point OW communication system, offers a cost-effective protocol-transparent link with high data rates (as 10 Gbps per wavelength). Such system allows to set up communication links between two locations whenever a free line of sight is pre- sent [2]. Typical wavelength of Free Space Optics system ranges from 800 to 1700 nm. For this rea- son, Optical Wireless communication system can be used in cellular backhauls, wireless MAN extensions, WLAN-to-WLAN connectivity in different environments, broadband access to remote or underserved areas [2] etc. Also, Optical Wireless system can be used not only for temporal installations, but as well in the face of a crisis for emergency and medical needs or permanent connections in last mile access without cabling.

However, a key disadvantage of Optical Wireless systems is its sensitivity to atmospheric conditions and its limited reliability. The resilience of such systems against fast-time-changing disruptions is dependent to different weather conditions as fog, snow, rain, clouds and etc. In general, for a higher resilience of such systems it is important to identify the appropri- ate acceptable level of service over weather-based disruptions.

Acceptable level of service can be re- fined based on the service disruption impact to a user. And the Quality of Service and Quality of Ex- perience plays a key role in this way.

The paper is organized as follows: Section 2 describes investigations in order to analyze the impact of different weather conditions to the links of Optical Wireless System. Section 3 gives the solution for the correlation of optical wireless signal attenuation during the different weather conditions (with main focus to fog and clouds) to the bit error rate para- meter during the service transmission over Optical Wireless system. The results from the correlation will be used as a main input for evaluation of the objective Quality of Experience metrics in Section 4. Finally, section 5 presents the conclusions and recommendations for further investigations.

2. IMPACT OF DIFFERENT WEATHER CONDITIONS TO OW LINKS

The atmosphere is composed of gas molecules, water vapor, aerosols, dust and pollutants, whose sizes are comparable to the wavelength of a typical optical carrier affecting the carrier wave propagation not common to a radio frequency (RF) system [2]. Absorption and scattering due to particulate matter may significantly attenuate the transmitted optical signal, while the wave-front quality of a signalcarrying laser beam transmitting through the atmosphere can be severely degraded, causing intensity fading, increased bit error rates, and random signal losses at the receiver. Due to this, the atmospheric channel for signal propagation over FSO communication has to deal with many external factors related to the different weather conditions [3]: rain, fog, sleet, snow, smog, clouds, different kinds of aerosols, variations in temperature and etc. All these weather conditions affect the wireless systems and Optical Wireless systems as well. It is just a difference in a scale of the affect to the parameters of OW communication performance.

The research group of the Institute of Microwave and Photonic Engineering in TU-Graz (Austria) has done a lot of work by investigating the impact of different weather conditions to the Optical Wireless communication, especially Free Space Optics sys- tems. One test of their many investigations was do- ne with a Multi-beam system [4]. This system was installed to connect the Department of Communications and Wave

Propagation to the "Observatory Lustbühel" [5]. Fig. 2 shows a terrain profile of this system [5]. The distance between FSO units was 2.7 km.

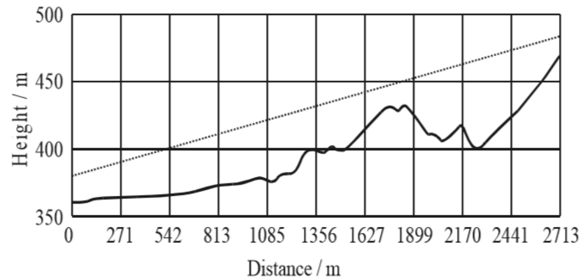

Figure 2. Terrain profile of FSO system [5].

Test data at 155 Mbps was sent from one FSO-unit to a distant FSO-unit. The received data was sent back (loop) to the first unit. As a reference to the link quality, weather data was recorded (including temperature, humidity, wind speed and direction and rain rate). The authors in this work [4] stated, that the main cause for failure of FSO links was fog. The same reason for OW system vulnerability was found in other investigation [6], comparing the fog attenuation for 850 and 950 nm wavelength in FSO system (Fig. 3).

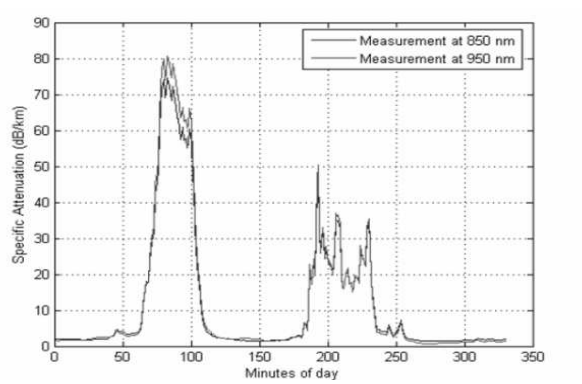

Figure 3. Influence of fog [6].

In general, fog and water clouds mostly affect FSO links due to the size of it droplets. The size of droplets is of the same order of magnitude as wave- length, which implies a high extinction efficiency, and their concentration is much larger than the one of rain or snow.

Rain is also an important attenuator for the optical signals. Fig. 4 shows that in period of a drizzle the mean power was decent by 2.5 dB at a rain rate of 2 mm/h.

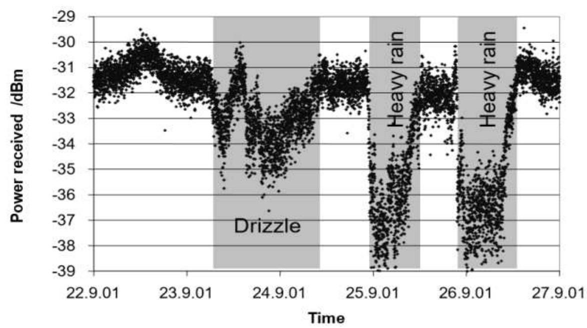

Figure 4. Influence of rain [7].

At the start of heavy rain with an average rain rate of 5 mm/h, accordingly the received power decent by 6 dB [7].

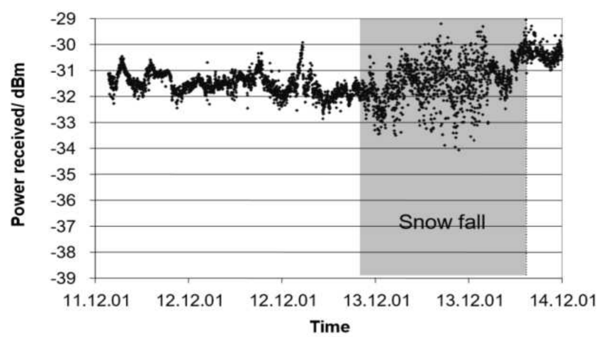

Figure 5. Snow influence [7].

Snow is usually constituted by aggregates of ice crystals and snowflakes have irregular shape or different compositions. A laser attenuation by falling snow can exceed 40 dB/km, depending on water content of snowflakes and on precipitation rate. In the investigation [7], which results are presented in Fig. 5, the received mean power of OW link stays unchanged, but the variance is increased significantly.

3. CORRELATION BETWEEN OPTICAL WIRELESS SIGNAL ATTENUATION AND QOS/QOE

As we can see in the previous section, performances characteristics of a data system over FSO links depend upon the atmosphere in which it propagates. Each wireless channel has a computable Bit Error Rate (BER), which is the probability of the occurrence of an error during data transfer over that link. As fog mostly affects the quality of FSO links comparing to other weather conditions such as rain or snow, further investigations were focused just on its effect.

Visibility is one of the parameters, which describes fog. The specific attenuation for both Kim and Kruse model is given by common empirical model [8]:

$$a(\lambda) = \frac{3.19}{V} \cdot \left(\frac{\lambda}{550}\right)^{-\gamma} \quad (1)$$

where λ is operating wavelength (nm), V is stands for visibility range(km) and g indicates the atmospheric attenuation coefficient according to Kim or Kruse model.

The BER calculation is given by the following formula:

$$BER = \frac{1}{2} erfc\left(\frac{1}{2}\sqrt{SNR}\right) \quad (2)$$

Quality assessment was carried out using SNR BER and MOS indicators, calculated by using hard- ware and software tools. Empirical values of BER transitions from an acceptable quality to the poor, according to the relationship between SNR and MOS, are presented in Table 1 [9].

For the evaluation of BER influence to QoS/QoE, we simulated two different types of fog (thick (0.2 m of visibility) and moderate (0.8 m of visibility) for two wavelengths: 1550 nm and 830 nm.

Table 1. Relationship between SNR BER and MOS [9]

MOS(%)	BER	SNR
100-81	$<10^{-8}$	>37
80-61	$10^{-8} < x < 10^{-6}$	31-37
60-41	$10^{-6} < x < 10^{-4}$	25-31
40-21	$10^{-4} < x < 10^{-2}$	20-25
<20	$>10^{-2}$	<20

We chose these parameters, because the main idea was to evaluate QoE for several types of in- formation: image and data.

4. EVALUATION OF OBJECTIVE QOS METRICS

The simulation was done using Matlab2017a software. At first, we calculated the received power and BER. The results are presented in Figs. 6 and 7.

It can be seen, that the impact of the fog to OW link depends on the length of waves over FSO system. The shorter wavelength in OW link gives a possibility to transmit service of a good quality at least ~100 meters further during a thick or moderate fog. The lines on the different BER values presents a level of perceived QoE by the user.

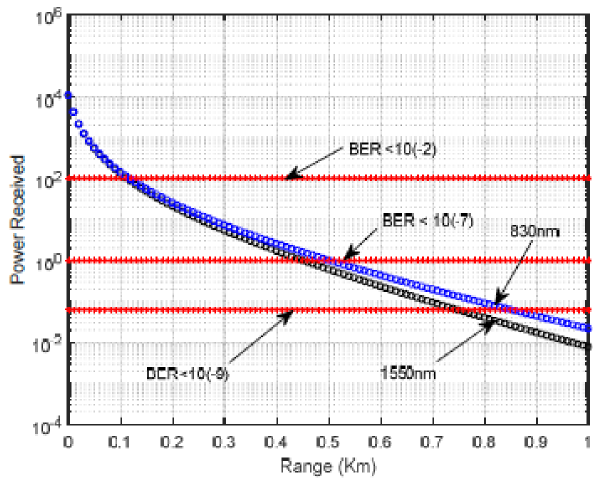

Figure 6. Thick fog.

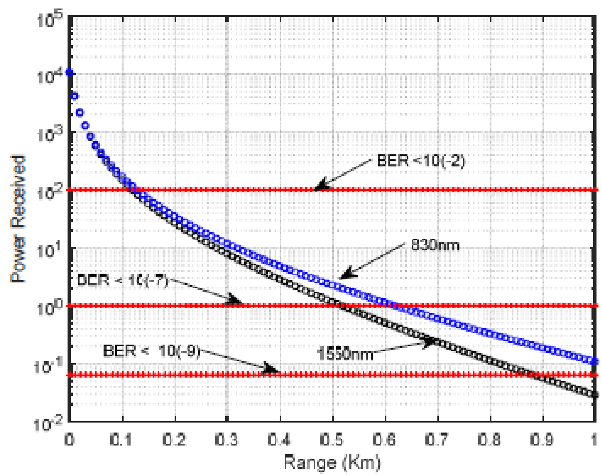

Figure 7. Moderate fog.

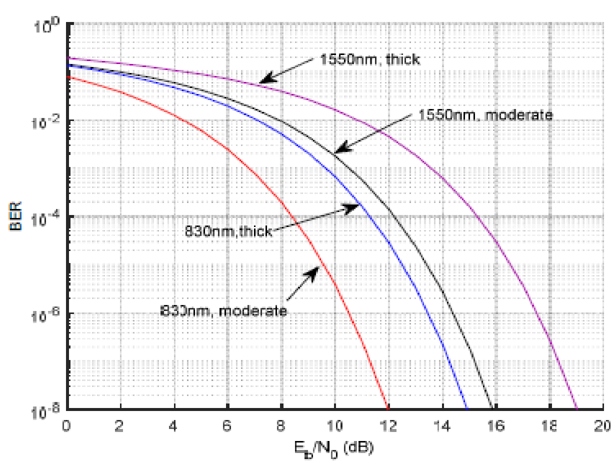

Figure 8. Relationship between BER and SNR.

The results in Fig. 8 showed, what range we need to have SNR (or Eb/N0) for different BER values.

For evaluation of MOS and QoE was used image and data information. The simulation was done for QAM-126 modulation, and SNR was between 4 and 27 dBm. The image simulation results are presented in the Fig. 9.

Figure 9. Relationship between MOS and QoE according BER.

The data simulation results are presented in Tables 2 and 3.

Table 2. Original information, which was sent.

#5+BDC123245798BDC123245798BDC123245798zxcvbnm

Table 3. Received data.

BER	MOS	QOE	Received data
$<10^{-2}$	<20	1.3	%»JCtq45718B DÃ527r4° DS1r #2>4792j:cfBnm
$<10^{-6}$	<37	3.6	"5+BEG123"457 9<BDÓ123r4571 YBLC10#245w98 zxcvbnm'
$<10^{-9}$	<92	4.9	#µ+BDC1232457 98BDC12324579 8BDC123245798 zxcfbnm

According to the obtained results in Figure 8 and in Table 3, it is seen, that the higher the error rate du- ring the transmission process, the lower the QoS and QoE parameters for different types of information (in our case for image and data). In this way, the influence of different intensity fog can cause the vulnerability in Optical Wireless system parameters, but the user can still use the different type of services, just with the different affect to real perceived quality.

6. CONCLUSION

The investigations showed, that using of shorter wavelengths can increase the resilience of OW systems during the fog. Also, it is a big difference in the scale of fog influence to a different type of services, which are transmitted over OW link. If the user receives data, the intensive fog can cause a big impact to the perceived quality of such service. However, if the user is using video service, he can feel just some single failures, but the service will be still in performance. The reason is a lower correlation between MOS and QoE. Due to this, a time interval occurs when the user sees the faults, but the service still can be used, even though that parameters of OW system starts to deteriorate. The main results from these investigations will help in further authors' work by creating a solution for an alert in order to react and prevent service performance degradation under the weather-based disruptions over wireless systems.

ACKNOWLEDGEMENT

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