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A Study on Malaysia Atmospheric Effect on Radio Over Free Space Optic through Radio Frequency Signal and Light Propagation in Fiber for Future Communication Development

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Abstract. This article presents the effects of haze attenuation on Radio over Free Space Optic (RoFSO) transmission system in KLIA Sepang, one of the towns in Malaysia. The haze condition which affects the FSO link transmissions was considered on October 2015 and on October 2017 at KLIA Sepang referring to the reading record of Air Pollution Index (API). In this paper, OptiSystem simulation software is used as a preliminary study before configuring the real RoFSO setup. We model the RoFSO by converting the radio frequency (RF) signal into light where the light source intensity is modulated with the RF signal. RF signal travels through free space while light propagates through fiber optic channel. Single-FSO and four-FSO channels are compared and analyzed in terms of bit-error-rate (BER), received optical power and eye diagram pattern. The results show that the performance of RoFSO with four-FSO channel system in comparison with single-channel has better receiver sensitivity and clear eye diagram. For future work, deploying multiple RoFSO system can fulfil the increasing demand for optimizing the communication bandwidth.

INTRODUCTION

Radio over Free Space Optics (RoFSO) is one of the promising technologies in future communications due to increasing demand for high speed, high bandwidth, low consumption of energy. The low-cost technology is critical due to the global race including the development of fifth generation (5G) mobile networks [1]. The RoFSO system is based on the concept of the combination of RoF system and FSO system, where the radio frequency signal and the optical signal need to experience modulation process at a transmitter before the modulated signal can be transmitted to a receiver [1].

The introduced RoFSO system in communications can overcome several problems such as the last mile problem and the problems of getting a reliable communication link in the areas where the installation of the fiber cables is difficult [2]. Therefore, there is no hassle with digging and burying fiber cable at the difficult geography places such as the sea, forest, and others. In addition, these issues are also revealed mainly in the underground of urban areas as well as in the rural places where the fiber infrastructures have not yet been constructed or upgraded due to high cost or low population area [3]. Consequently, it shows that RoFSO provides a wireless solution to the last mile connection between two points in the areas of difficult physical channel access for broadband services.

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The transmission of the data through FSO also provides a good data security, requires no license as well as ease deployment in terms of data transmission. However, there is a drawback of the transmission through the FSO network, where some weather turbulence factors including haze, rain and fog may degrade the quality of the signal data [2].

In this paper, Optisystem simulation is used to study the effect of haze weather conditions in Malaysia on the performance of modulated signal transmission through RoFSO network before deploying the real RoFSO system. We first simulate the transmission of the signal via single-channel FSO network and compared the performance with four-FSO channels using Wavelength Division Multiplexing (WDM) approach. The performance is evaluated in terms of Bit error rate (BER), received optical power and eye diagram pattern. We also simulate the effect of length of the optical fiber on the performance of four-channel RoFSO network, where the modulated signal is firstly propagated in the fiber before reaching the FSO antennas. From the obtained results, the distance between the transmitter and the receptor for obtaining the quality of the received signals can be estimated.

METHODOLOGY

Design RoFSO System Model

A. RoFSO Communication Model

In RoFSO, the message signal is transferred into a suitable form, conducted by a transmitter. Meanwhile, the channel acts as a medium for the message to be sent between the transmitter's output and the receiver's input. The receiver side is used to receive the transmitted signal and then convert the signal into the original form. For the RoFSO system as shown in Fig. 1, two channels were used, which were fiber optic and free space. Firstly, the RF signal was modulated with the optical signal at the transmitter before propagated through a single mode fiber (SMF) in the fiber optic channel. The SMF functions as a coupler between the modulator and the FSO antenna. The transmission of modulated signal in both fiber optic channel and free space channel may encounter the disturbances like noise and interference, which can interrupt and reduce the quality of the signal transmitted. Other than using only a single-FSO channel for the transmission, it is also possible to utilize multiple FSO channels. At the receiver, the modulated signal was captured by another receptor of FSO antenna(s) and then demodulated the signal to obtain the required signal. Figure 2 shows a suggested deployment of RoFSO system between two buildings using single FSO channel and four FSO channels.

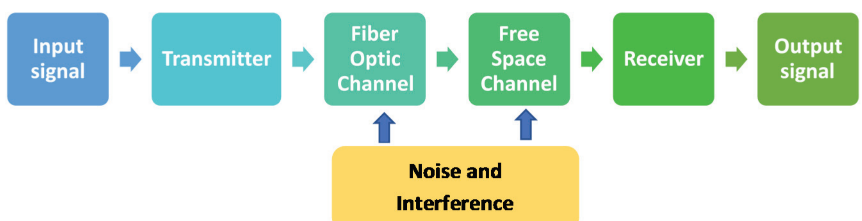


FIGURE 1. Basic block system of RoFSO system

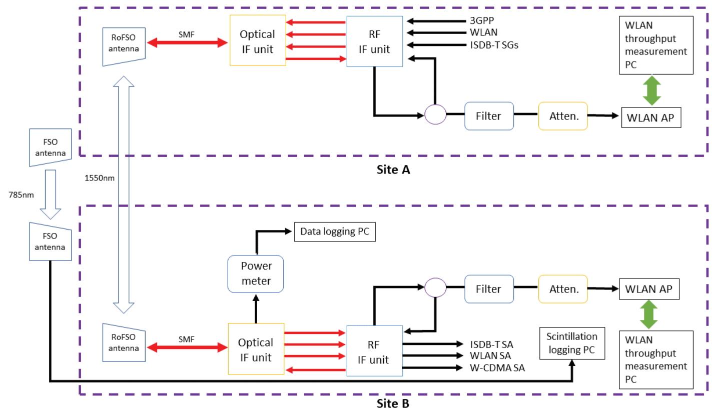


FIGURE 2. Suggested deployment of using single-channel and four-channels for RoFSO transmission between two buildings.

B. Main Design for Single-FSO Channel and Four-FSO Channels in RoFSO System

The overall system design shows in Fig. 3 and 4 were designed in OptiSystem software for single-FSO channel and four-FSO channels respectively consisting stages of a transmitter, a link channel, and a receiver. The details of each stage and equipment used will be thoroughly discussed in the following sections.

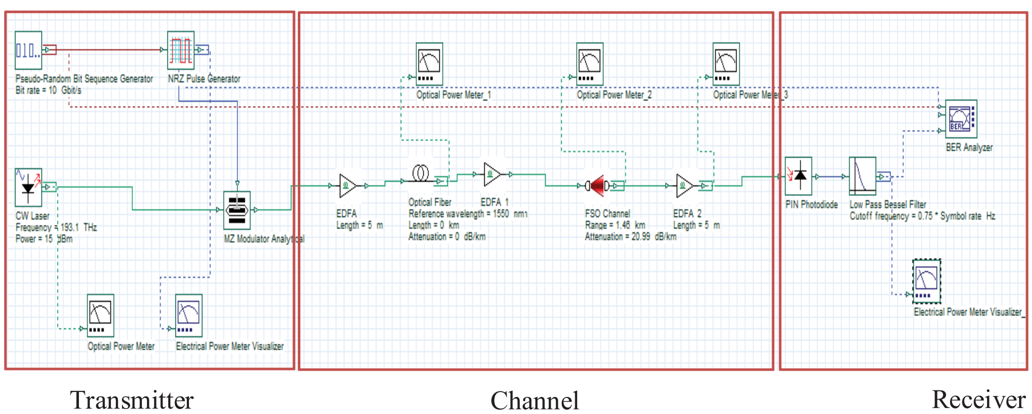


FIGURE 3. RoFSO System with the use of Single FSO Channel

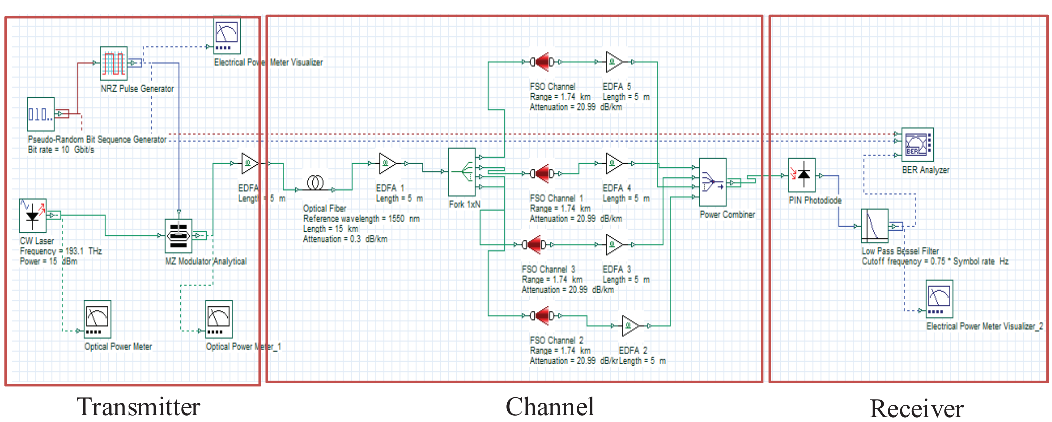


FIGURE 4. RoFSO System with the use of Four FSO Channel

C. Transmitter

The main setup at transmitter is to convert the electrical signal into an optical form and launching the modulated optical signal into the optical fiber channel. The wavelength of 1550 nm is typically well suited for RoFSO networks because it provides less attenuation compared to 1310nm [3]. A Continuous Wave (CW) laser that resonates at 193.1 THz and 193.2 THz emitted an optical light and generated the optical signal to be modulated by the Mach-Zehnder Modulator (MZM) modulator. A Pseudo Random Bit Sequence (PRBS) generator that generated random binary sequence at a bit rate of 10Gbps modulated the data signal with another generator, which was Non-Return Zero (NRZ) generator. The NRZ pulse generator was used to convert the binary sequence into an electrical signal. The NRZ pulse generator was chosen because it performs better for long haul communication based on the Q factor and eye diagram [9].

The MZM device is one of the electro optic modulators that use electro-optic effect for light modulating [10]. By using this modulator, it can provide lesser chirp, tolerant to chromatic dispersion and low drive voltage. Indeed, it is in high performance, thus suitable for developing next generation transmission system [10]. The MZM modulator modulated the incoming optical carrier signal from the CW laser with the electrical signal from the NRZ pulse generator. Then, the modulated signal was passed to the optical fiber. Four-FSO channels setup is shown in Fig. 4. In order to connect four-FSO channels, a fork and a power combiner were used. The fork copied the input optical power signal into four output signals whereas the power combiner combined the four optical output signals.

D. Channel Model

The combination of two types of channel models which were optical fiber and free space used the same radio frequency but in different propagation concepts due to the different medium. Light carries information in fiber optic glass was based on the concept of total internal reflection. Both channel models have advantages and limitations in a way to distribute the data to the end user. For instance, the use of optical fiber cable is more robust to the radio frequency interference, low attenuation loss, wide bandwidth capacity for microwave signal transmission in a wireless network as well as easier to install and to maintain the system [11]. The light travelling in the glass offers low attenuation compare to propagating in the atmosphere [10].

Atmospheric air is the transmission medium for FSO communication. The light signal can be attenuated due to the atmospheric conditions such as rain, haze, dust and fog. This atmospheric attenuation is one of the main causes of the degradation of the signal in addition to geometric losses. Other sub-factors of losses are scintillation, turbulence fading and multipath fading [4]. Therefore, it is important to take into account the effect of atmospheric attenuations. The haze attenuation, β_haze (dB/km) equation is given by eq. (1) [6]

$$\beta_{haze} = \left(\frac{3.91}{V}\right)\left(\frac{\lambda}{550}\right)^{-q} \qquad (1) \qquad\qquad q = \begin{cases} 1.6 & V > 50km \\ 1.3 & 6km < V < 50km \\ 0.585V^{1/3} & V < 6km \end{cases}$$

Where V is the visibility in km, λ is the wavelength in nm and q is the coefficient dependent on the size distribution of the scattering particles. Meanwhile, the rain attenuation can be constructed as in the eq. (2) [7]:

$$\gamma_{rain} = k.R^{\alpha} \qquad (2)$$

Where γ_{rain} is the rain attenuation (dB/km), R is the rain intensity (mm/hr) while k and α are the rain coefficients. Next, the fog attenuation, becomes the most unfavorable attenuation factor over all types of atmospheric attenuation due to very high value. The attenuation is calculated from Kruse model by eq. (3) [8]:

$$\gamma_{fog} = \left(\frac{17}{V}\right)\left(\frac{\lambda}{550}\right)^{-q} \qquad (3)$$

Where γ_{fog} is the fog attenuation (dB/km), V is the visibility in km and q is the particle size distribution. To make it simpler, the attenuation increases when the visibilities are low, thus the availability of the optical signal transmissions in the free space also decrease. In this work, the loss attenuation in RoFSO network was achieved by combining the losses in the RoF with the FSO system based on the theoretical formula mimicked the real transmission.

The performance of free space optical system is highly affected by the weather conditions, therefore, it is necessary to enhance the signal strength, where the weak optical signal was amplified to the optimum level by using an Erbium Doped Fiber Amplifier (EDFA). It is because the signals may require undergoing amplification process to boost the power of the signal after traveled for a long distance between the source and the destination.

E. Receiver

At the receiver, a PIN photodetector that has a good quantum efficiency was used to detect and demodulate optical signal before passsed to the filter [8]. A low pass Bessel filter with cutoff frequency was to remove the higher frequency components and to filter noises from the signal. For analysis, there are several visualizer tools of BER analyzer and power meter were used to analyze the performance of minimum BER. The BER is the number of received bits of the data stream from the communication channel that has been altered due to noise, interference and distortion orbit synchronization errors [13]. The value of minimum BER should less than 10^{-9} as stated in the International Telecommunication Union (ITU telecom). Overall, it is important to deeply understand the characteristics and functions of each component to get the optimal performance system.

Verify RoFSO System Performance

A. ***Visibility Data for Haze Condition***

Visibility was characterized by the possibility of the maximum range that the normal human eye can be seen and possibly measured within kilometers. This research was focused on the effect of haze at Kuala Lumpur International Airport (KLIA) Sepang region on October 2015 and on October 2017, where the data was collected from Malaysia Meteorological Department (MMD) Petaling Jaya. Nilai which is closer to Sepang was faced the worst haze problem on October 2015 with the reading record of Air Pollution Index (API) was 152 from Utusan Malaysia Online and Astro Awani [14], [15]. The summarization haze data from MMD is shown in table 1. The lowest visibility for October 2015 falls into the moderate fog category while for October 2017 falls into the thin fog with the values are 0.5 km and 1.5 km respectively.

TABLE 1. Visibility Data for KLIA Sepang on October 2015 and October 2017

Date	***Visibility (km)***					
	Min	***Condition***	***Max***	***Condition***	***Avg***	***Condition***
Oct-15	0.5	Moderate fog	13	Clear	3	Haze
Oct-17	1.5	Thin Fog	14	Clear	10	Light Haze

Standardization of the data was according to the International Telecommunication Union-Radio Communication of ITU-R P.1817 and ITU-R P.1814 [16]. The International Visibility Code displays the attenuation for various climatic conditions from very clear periods to dense fog and the visibility from 50 m to 50 km accordingly as is shown in table 2 [14].

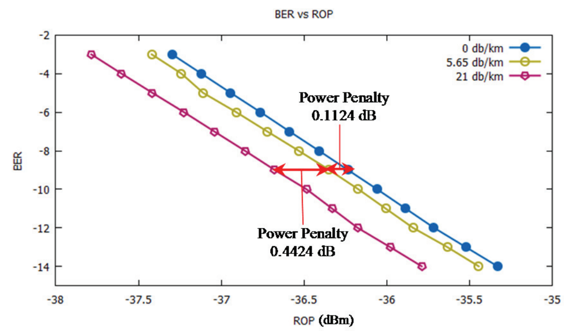
TABLE 2. International Visibility Codes [14]

Weather Condition	***Visibility (km)***	***Attenuation (dB/km)***
Dense fog	0.0 to 0.05	0 to 315
Thick fog	0.2	75
Moderate fog	0.5	28.9
Light fog	0.77 to 1	18.3 to 13.8
Thin fog	1.9 to 2	6.9 to 6.6
Haze	2.8 to 4	4.6 to 3.1
Light haze	5.9 to 10	2 to 1.1
Clear	18.1 to 20	0.6 to 0.54
Very clear	23 to 50	0.47 to 0.19

SIMULATION RESULTS AND DISCUSSIONS

A. RoFSO with Single-FSO Channel

To verify the feasibility of our proposal, at first, we simulate a single-FSO channel transmission link. The minimum visibility data were taken at the minimum visibility value in October 2015 and October 2017. Firstly, 0-dB/km attenuation value is applied as back-to-back data reference. Reference data are data that define no attenuation value added in the system.



*ROP is Received Optical Power

FIGURE 5. BER versus ROP for Various Haze Attenuation in single RoFSO channel.

The BER curves for all attenuation values at different ROP values are plotted in Fig. 5. We achieved error-free operation for all haze attenuation values with a small power penalty less than 0.44-dB compared to back-to-back 0-dB/km attenuation. Different value of attenuation channel gave different shape of eye diagram as well as BER value. The FSO eye diagram at the BER of 10^{-9} during 5.65-dB/km and 21-dB/km attenuation setup are depicted in Fig. 6 and 7. Clear and wide opened eye diagram at both channels were obtained in both attenuation values.

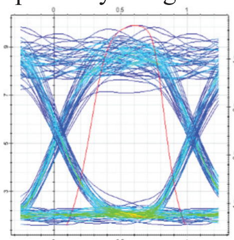


FIGURE 6. Eye Diagram for 5.65dB/km attenuation

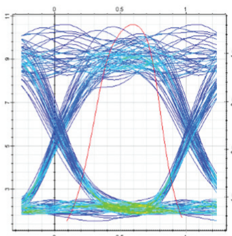
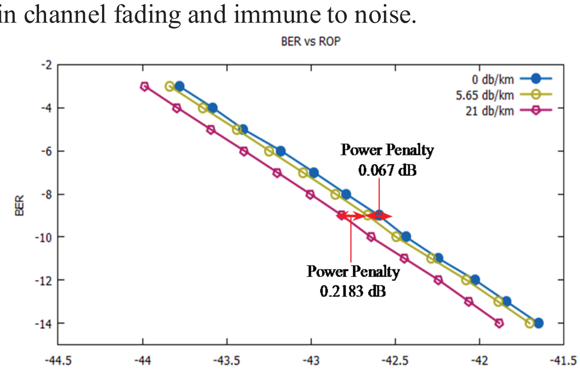


FIGURE 7. Eye Diagram for 21dB/km attenuation

B. RoFSO with Four-FSO Channel at 0-km Optical Fiber length

The measured BER performances of four-FSO channels at various haze attenuation are plotted in Fig. 8. We achieved error-free operation for all attenuation settings with small power penalty of less than 0.21-dB compared to back-to-back 0-dB/km attenuation. These results show that the multiple FSO channels have the ability to reduce geometrical loss, more robust in channel fading and immune to noise.



*ROP is Received Optical Power

FIGURE 8. BER versus ROP for Haze Attenuation in RoFSO System with Four-FSO channels

At the 0-dB/km attenuation, the maximum length of FSO is performed to be 155km with 10^{-9} of BER value which exhibits longer than the system using the single FSO channel, which is 74.5km before. Next, the longest distance for 5.65-dB/km is 5.22-km while for 21-dB/km, it is 1.84km. Both distances are longer than the distance when applying the single FSO channel, which are 4.37-km for 5.65-dB/km and 1.60-km for 21-dB/km. The eye diagram structure for 5.65 dB/km and 21 dB/km attenuation with 10^{-9} of BER value shown in Fig. 9 and 10. The eye height for 5.65 dB/km and 21 dB/km are 0.00077 and 0.00075. Based on the simulation result, the longer the distance, and the shorter the eye-opening due to losses along the channel.

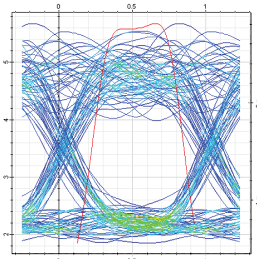


FIGURE 9. Eye Diagram for BER 10^{-9} for 5.65dB/km

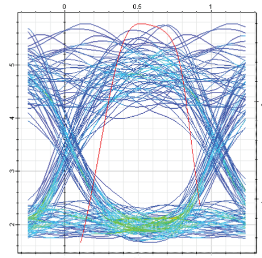
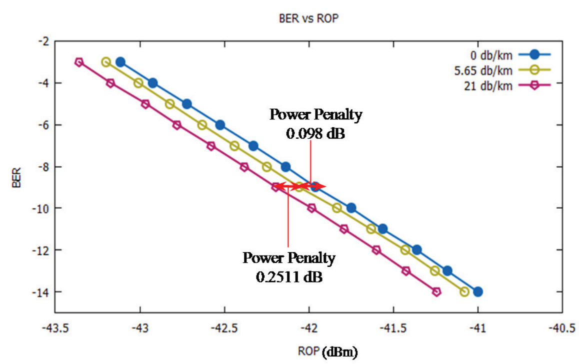


FIGURE 10. Eye Diagram for BER 10^{-9} for 21dB/km

C. RoFSO with 4-FSO Channel at 15-km Optical Fiber length.

The result of system design for FSO channel with three haze attenuation value and fixed optical fiber length which is 15-km as shown in Fig. 11. Comparing the result from system with zero optical fiber length, it shows the increasing of received optical power. The received optical power in Fig. 10 for 21 dB/km with 15km fiber length is -42.19 dBm higher than optical power in the system in Fig. 7 with zero fiber cable length which is -42.82 dBm. Hence, inserting optical fiber helps in increasing the output optical power. In contrast, the distance of FSO channel become slightly shorter due to the additional losses of the optical fiber. The power penalty for 5.65 dB/km is 0.098dB while 0.2511dB is for 21 dB/km.



*ROP is Received Optical Power

FIGURE 11. BER versus ROP

CONCLUSION

The signal performance undergoes degradation when the haze attenuation value increases as well as FSO range and optical fiber length. As the length of both channels increase, the value of power penalty will be increased. Based on the simulation results, the integration of RoFSO system will become the next generation optical communication network because of its good performance in data transmission signals. Furthermore, RoFSO with multiple FSO channels has the capability of tackling the effect of Malaysian haze weather condition due to the significant improvement on the link distance, minimum BER value, and optical power penalty.

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