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Optimization Free Space Optic (FSO) Design with Kim Model Using Space Diversity

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Abstract - The development of communication services in remote rural areas is difficult to use cable-based systems such as Digital Subscriber Line (DSL) and FTTx. One solution to solve this problem is to use a wireless system such as radio communication. Free Space Optic (FSO) communication system is a better choice compared to radio communication because of the flexibility of frequency usage. One of the problems of the FSO communication system is the range not too far. The range of the FSO can be increased by using the space diversity method. This study compared FSO systems that not use space diversity and FSO systems that use space diversity in three weather conditions, namely clear, haze, and fog. In taking data results using Kim model propagation with variations in the range between 100 – 2000 meters. The modulation used in this study is external modulation. The result of the analysis of FSO performance after adding space diversity, the range of FSO increases as far as 1200 meters when the condition is clear. During the haze condition, the FSO range increase as far as 800 meters. During the fog condition, the FSO range has increased as far as 300 meters. By adding space diversity, the Q-factor value has increased, and BER (Bit Error Rate) has decreased.

Keywords – FSO, Space diversity, weather condition

I. INTRODUCTION

Communication is something that is needed and becomes very important for people's lives. With the development of technology, communication becomes a straightforward thing because it does not require a long time to be able to communicate with other users. With these community needs, it certainly must be supported by the availability of network infrastructure and services.

Existing solutions such as Digital Subscriber Line (DSL) technology are complicated to apply to remote areas because it will be costly and also unable to support mobile services at high speed [1]. Then for fiber optic technology, it may even be necessary to dig roads and to build foundations to plant fiber optic cables, so the installation costs require a high cost. Other conventional solutions are using wireless communication systems or using radiofrequency. However, radiofrequency is very susceptible to interference and requires permission to use frequency [2].

Another solution to the problem that has been explained is using a free space optical communication system (FSO). Free-space optics (FSO) is one of the new optical communication technology which makes it possible to obtain the wireless optical communication with high data rate. This technology reduces the difficulty while laying optical fibers [3]. [4]. FSO is a line-of-sight technology that uses a laser and photodetector to connect between two wireless users. FSO can transmit data, sound or video with a speed that can reach 2.5 Gbps. The FSO unit consists of optical transceivers with lasers (transmitters) and photodetectors (receivers) to provide full-duplex (bi-directional) capabilities [5].

The Free Space Optic (FSO) communication system is an optical communication system that uses the atmosphere as propagation [6]. The FSO system uses infrared laser rays that are not visible in the range of 750 nm to 1550 nm. FSO provides transmission of point-to-point communication through the atmosphere using optical signals as to frequency carriers [7]. FSO communication is free of licensing. FSO can simultaneously send data, voice, and video communication over the air using light beams. FSO has several advantages including having a wide bandwidth, small power consumption, no need for frequency usage permits, more secure and can be integrated with other systems [8] [9] [10] [11].

Previous research discussed the performance of FSO communication systems using cell-site diversity. The result is the diversity gain obtained an increase in SNR values related to the length of the track. The longer the path used, the greater the diversity gain value. This is related to the attenuation value which is comparable to the length of the track [12].

This study discusses the performance of the free-space optical communication system using a space diversity technique with Kim model. Kim model is a propagation model that helps to determine the value of attenuation. Space diversity is used to optimize the design of the FSO to handle the FSO problem; that is, the distance of the FSO range is not too far. Space diversity is one of several wireless diversity schemes that uses two or more antennas to improve the quality and reliability of wireless links [13]. The space diversity technique used is the combining technique. This technique is used so that the FSO communication system can still send information to the maximum.

II. RESEARCH METHOD

The method in this study is using OptiSystem software. The display of FSO simulation without space diversity technique is shown in Fig.1, while the FSO simulation using space diversity technique is shown in Fig.2. The parameters used to design the FSO network use the datasheet of Acorn Technologies Ltd., the G500 brand. The parameters for designing the FSO network are shown in Table 1.

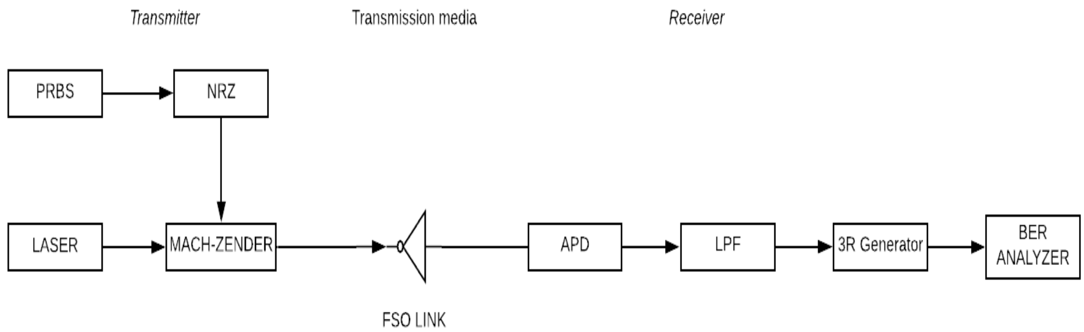

Fig.1. FSO Simulation Without Space Diversity Technique

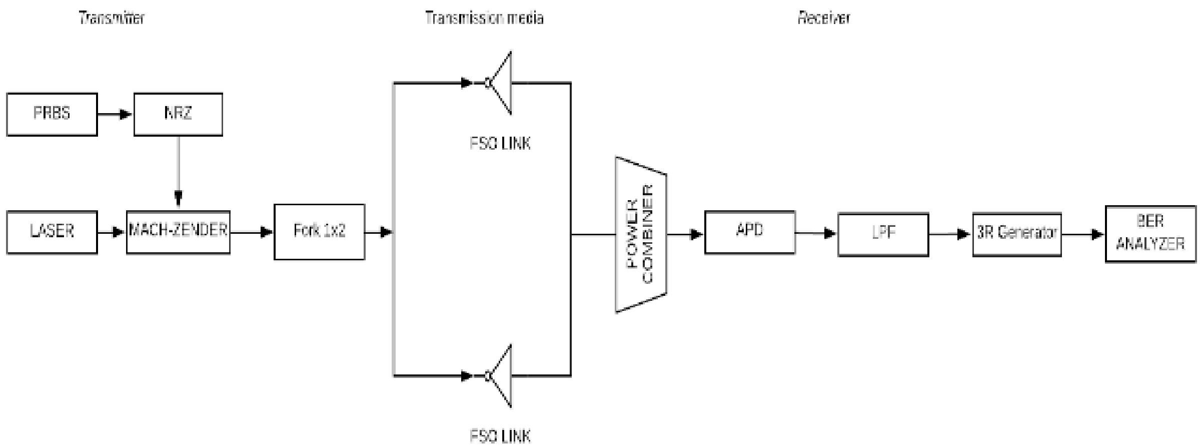

Fig.2. FSO Simulation Using Space Diversity Technique

Table 1. FSO Network Parameter

Parameter	Value	Unit
Bit rate	10	Gbps
Transmitter power	14,8	dBm
Wavelength	780	nm
Beam divergence	5	mrad
Transmitter aperture diameter	2	cm
Receiver aperture diameter	7,5	cm
Low pass filter Cut off frequency	0,75*Bit Rate	

The FSO network used a CW laser source and APD photodetector. FSO system configuration used external modulation. In the case of external modulation, an external device is used, which varies the characteristics of the carrier following the modulating signal. These systems are capable of utilizing the full power of the source. The distance between TX/RX is determined by the range of 100 m - 2000 m.

Weakening because of the fog can be predicted by applying the theory of "Mie Scattering." However, this theory requires detailed information about fog parameters. Therefore an alternative approach is based on visibility range information, where attenuation due to fog is predicted using a general empirical model. The 550 nm wavelength is usually used as the reference wavelength of the visibility range. Equation 2 defines the specific damping of fog for "Mie Scattering" [15],

$$\beta(\lambda) = \frac{3{,}91}{\nu}\left(\frac{\lambda}{550}\right)^{-p} \quad (1)$$

with ν (km) is the range of visibility, λ (nm) is the operating wavelength, and p is the scattering size distribution coefficient.

In order to predict optical attenuation statistics from visibility statistics and the FSO system range, the relationship between visibility and attenuation must be known. The term called "specific attenuation" is used to represent attenuation per unit length expressed in dB/km with the formula [14],

$$\beta(\lambda) = \frac{1}{R} 10 \log \frac{P_O}{P_R} = \frac{1}{R} 10 \log e^{\gamma(\lambda)R} \quad (2)$$

where R is the length of the link, the optical power P_O emitted from the transmitter. P_R is optical power at a distance of R, and R is the coefficient of attenuation of the atmosphere. The value of $e^{\gamma(\lambda)R}$ obtained from $e^{\beta(\lambda)}$, with β(λ) is the result from β(λ) "Mie Scattering."

Based on Kim's model, p can be calculated using the following equation,

$$p = \begin{cases} 1{,}6 & 50 < v \\ 1{,}3 & 6 < v < 50 \\ 0{,}16V + 0{,}34 & 1 < v < 6 \\ V - 0{,}5 & 0{,}5 < v < 1 \\ 0 & v < 0{,}5 \end{cases} \quad (3)$$

Different weather conditions can be determined based on the value of the visibility range. Table 2 summarizes the visibility range for different weather conditions.

Table 2. Visibility Value Based on Weather Conditions

Weather Conditions	Visibility (km)
Thick fog	0,2
Moderate fog	0,5
Light fig	0,770 – 1
Thin fog/heavy rain	1,9 – 2
Haze/ medium rain	2,8 – 4
Light haze/light rain	5,9 – 10
Clear/drizzle	18 – 20
Very clear	23 – 50

Based on Table 2, it is known that during clear condition, the visibility is 23 - 50 km, while during haze condition, the visibility is 2,8 - 4 km, and during fog condition, the visibility is 0,5 km.

Based on the formula described in (1), (2) and (3), the attenuation value is obtained, as shown in Table 3 below.

Table 3. Attenuation Value

Weather	Value	Unit
Clear	0,46	dB/km
Haze	4,60	dB/km
Fog	33,96	dB/km

III. RESULT

The results of the data obtained from simulations are varied in three conditions, namely in clear, haze, and fog. The design parameters are shown in Table 1, while the attenuation value is shown in Table 2. The FSO performance will be analyzed using the BER analyzer, which is installed after 3R Generator in the FSO design, and the parameters to be analyzed are the Q-factor value and BER value (Bit Error Rate). Q-factor values in clear conditions are shown in Table 4.

Table 4. Comparison of Q-Factor Value when Clear Condition

Distance (km)	Q-factor value without space diversity	Q-factor value with space diversity
0,1	192,97	297,128
0,2	75,393	132,491
0,3	40,367	77,4535
0,4	25,559	50,8338
0,5	17,2985	35,6931
0,6	12,3657	26,2496

Distance (km)	**Q-factor value without space diversity**	**Q-factor value with space diversity**
0,7	9,22355	19,9885
0,8	7,11308	15,6467
0,9	5,63379	12,5287
1	4,56077	10,2268
1,1	3,75874	8,48177
1,2	3,14465	7,13171
1,3	2,66474	6,06852
1,4	2,28138	5,21814
1,5	1,96314	4,52857
1,6	0	3,96256
1,7	0	3,49288
1,8	0	3,09932
1,9	0	2,76663
2	0	2,48314

For BER value of the FSO system when clear conditions are shown in the following Fig.3.

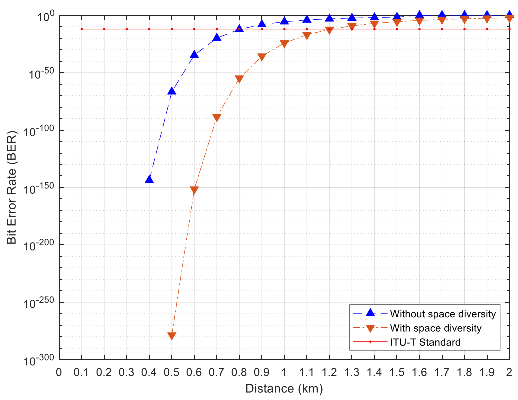

Fig.3. Comparison BER Value when Clear Condition

Based on Table 4 and Fig.3, it can be seen that the FSO system using space diversity better than the FSO system without space diversity.

Next is the comparison of Q-factor values when the rain conditions are shown in Table 5.

Table 5. Comparison of Q-Factor Value when Haze Condition

Distance (km)	**Q-factor value without space diversity**	**Q-factor value with *space diversity***
0,1	181,446	281,539
0,2	65,3948	117,278
0,3	32,4499	63,182
0,4	18,4265	37,8008
0,5	11,2388	24,0295
0,6	7,25772	15,9482
0,7	4,89886	10,9561
0,8	3,4229	7,74491
0,9	2,45765	5,60808
1	0	4,14636

Distance (km)	**Q-factor value without space diversity**	**Q-factor value with *space diversity***
1,1	0	3,12222
1,2	0	2,38955
1,3	0	0
1,4	0	0

For BER value of the FSO system when haze conditions are shown in the following Fig.4,

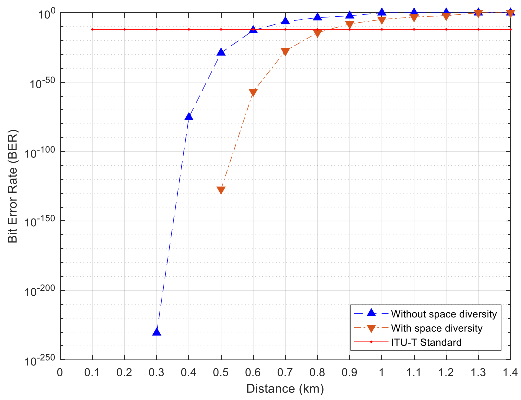

Fig.1. Comparison BER Value when Haze Condition

By using space diversity, Q-factor has increased, and BER value has decreased compared to the FSO system without space diversity.

Then the last experiment is when the fog conditions, the Q-factor value is shown in the following Table 6.

Table 6. Comparison of Q-factor Value when Fog Condition

Distance (km)	**Q-factor value without *space diversity***	**Q-factor value with *space diversity***
0,1	115,148	190,009
0,2	22,4221	45,1531
0,3	5,26431	11,7403
0,4	0	3,26879
0,5	0	0

Comparison of the BER value when the fog conditions are shown in the following Fig.5.

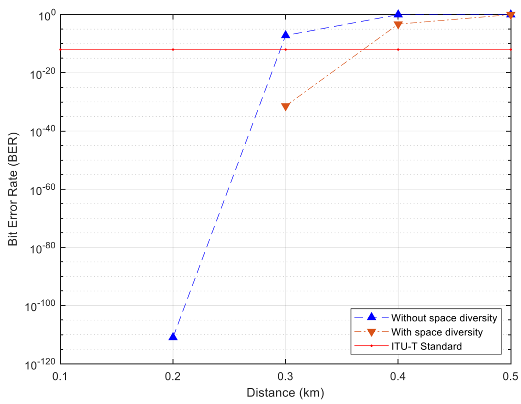

Fig.2. Comparison of BER Value when Fog Condition

During the fog condition, the performance of FSO becomes not optimal; with space diversity, there is an increase in the range of distance even though not significant.

IV. DISCUSSION

Based on Table 3 and Fig.3, according to ITU-T standards, which state that good Q-factor values are not worse than 7,03, and good BER values are not worse than $1x10^{-12}$ [16], it can be known FSO range when not using the diversity space as far as 800 meters. In comparison, by adding the space diversity technique, the FSO range is 1200 meters. By adding the space diversity technique, the Q-factor value increases, and the BER value decreases compared to the FSO system that does not use space diversity.

During the rain conditions, the performance of FSO decreases because raindrops inhibit the laser beam path. Based on Table 4 and Fig.4, according to ITU-T standards which state that good Q-factor values are not worse than 7,03, and good BER values are not worse than $1x10^{-12}$ [16], it can be known FSO range when not using the space diversity as far as 600 meters. In comparison, by adding space diversity techniques, the FSO range is 800 meters. The Q-factor value increases, and the BER value decreases by adding space diversity.

During the fog conditions, the performance of FSO becomes not optimal. Mist particles block the laser due to absorption, scattering, and reflection. Based on Table 5 and Fig.5, according to ITU-T, which states that good Q-factor values are not worse than 7,03 and good BER values are not worse than $1x10^{-12}$ [16], it can be known FSO range when not using space diversity as far as 200 meters. In contrast, by adding the space diversity technique, the FSO range is 300 meters. The addition of space diversity also affects the increase of the Q-factor value and the decreasing of the BER value.

The simulation has been done with variations in weather conditions such as clear, haze, and fog with an FSO system that not use space diversity and FSO systems that use space diversity. It is known that FSO performance FSO performance is1 very influential on various environmental factors, including fog, snow, rain, and others. This factor causes a decrease in the signal power received. Of all environmental factors, atmospheric attenuation is usually very influential by fog because the particle size of fog is proportional to the wavelength in the FSO system. The factor mentioned above can change the characteristics of an optical signal, or it can completely block the entry of light due to absorption, scattering, and reflection. FSO performance is excellent when the weather conditions are clear; there is an increase in the FSO range to 1200 meters when adding space diversity. When the rain conditions FSO performance decreases, the distance of the FSO reaches by adding 800 meters of diversity space. During fog conditions, the FSO's performance is not optimal. By adding space diversity, the distance of the FSO range has increased to as far as 300 meters.

V. CONCLUSION

Based on the discussion about optimization FSO design with Kim's model using space diversity, it can be concluded that weather conditions strongly influence the performance of FSO. During the rain condition, FSO performance decreases because raindrops inhibit the laser beam path, during fog conditions, fog particles block the laser due to absorption, scattering, and reflection. By adding space diversity techniques, the distance of the FSO range has increased. The range has increased as far as 1200 meters when the condition is clear. During the haze condition, the FSO range increased as far as 1000 meters, and in fog conditions, the FSO range has increased as far as 3000 meters. The Q-factor value has increased, and BER has decreased, which indicates that the FSO's performance is getting better.

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