Journal of Theoretical and Applied Information Technology
31st January 2024. Vol.102. No 2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

HYBRID MODULATION TECHNIQUE TO IMPROVE RECEIVER SENSITIVITY FOR FSO LINK PROPAGATION

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ABSTRACT

Free space optical (FSO) communication is now become a main communication due to the ability of propagation channel to operate up to Terabit per sec (Tbs) and can support high number user. The FSO suffer when experience severe weather condition. Apart from that FSO also facing threshold problem especially related with Amplitude Shift Keying - Onn Off Keying (ASK-OOK) when dealing poor signal and the biggest effect is high noise presence at receiver which led the signal to deteriorate. In this research proposed new development of transmitter and receiver design in order to reduce the impact of atmospheric attenuation and increase receiver sensitivity. In this paper focus on the analysis performance related bit rate which will compare with conventional amplitude shift keying (ASK) approach. Simulation result will be used to measure the performance and comparison between conventional and new proposed modulation double transmission balance receiver (DTBR) will also be presented. It was anticipated that proposed technique which offer a simple and inexpensive procedure capable of increasing received power, receiver sensitivity, and decreasing bit error rate would be used. The measurement of result will involve the effect of geometrical loss, data bit rate and distance propagation. Four level of synchronous transport module (STM) which is STM1(155Mbps), STM4(622Mbps), STM16(2.5Gbps) and STM64(10Gbps) will be compare the performance of bit rate. Meanwhile two different distances will test to measure the ability system extend the range transmission. From the result, the DTBR can increase 25% improvement as compare to conventional ASK.

Keywords: *Free Space Optical, Conventional ASK, Geometrical Loss, Bit Error Rate*

1. INTRODUCTION

The Free Space Optics (FSO) can be defined as an optical communication technology that uses light which usually uses a LASER source and propagate via free space to transmit data between two points [1]. This technology has the same characteristic with the fiber optic communications but only distinguished in term of medium propagation. The data of optic fiber communication are transmitted by modulated laser light in cable, while FSO data are transmitted in a narrow beam through the atmosphere. Light travels through air faster than it does through glass, so it is fair to classify FSO as optical communications at the speed of light [2].

In terms of advantages of FSO technology communication over fiber communication, the FSO is not requiring the licensing from the Federal Communications Commission (FCC). Unlike the RF communication need the licensing for frequency allocation due to RF use the frequency that less than 300 GHz. Apart from that the FSO can support the bandwidth up to 2.5Gbps if compare to RF limited to 622Mbps. The further study has successfully tested 160Gbps in laboratories and speed could potentially be able to reach Terabit range [3]. The FSO also has an attractive alternative to the excessively high cost of digging the street to lay the fiber and requiring permission from authorities for installation. This technology transmission only needs a place on a roof or behind a window to set up a transceiver. The duration of installation can be made over within a few hours or one day.

Behind the advanced of this technology, the obvious limitation in FSO is vulnerable to weather condition. This led this technology not applicable for long distance in terrestrial FSO. This technology also needs a line of sight (LOS) transmission to operate. Any blocking over the laser light will cause the receiver not received the signal and drag to loss of communication data [5]. For instance, the flying bird across the laser beam propagation is most normal cases that block the laser light. Moreover, the building movement also can impair the link performance. This is because the arising of pointing error in FSO system [6].

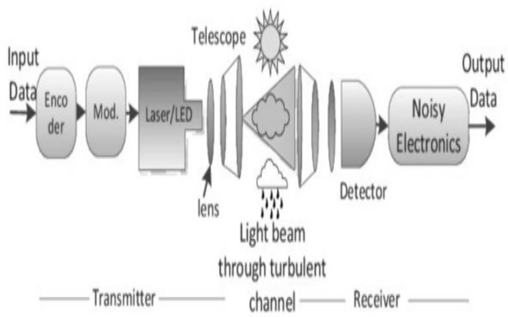


Figure 1. Basic of FSO communication system

(a)

(b)

Figure 2. Example difference visibility of FSO facing by FSO transmission due to foggy and haze weather

Atmospheric scintillation is attributed to temperature inhomogeneity, as reported by [18]. When the optical beam travels through the atmosphere, it encounters both constructive and destructive interference, which may weaken the signal. When the distance between transmitter and receiver is more than 1 km, scintillation may drastically reduce FSO connection availability and performance.

The typical ASK - OOK modulation method is a common basic modulation technique that is now employed in commercially available terrestrial FSO systems [19]. Nevertheless, when turbulence is present, the received signal level fluctuates, and the threshold detector must watch this variation in order to find the best decision point. As a consequence, a considerable design challenge will be required, since channel noise and fading will need to be continuously monitored for the OOK in FSO to work ideally. Ignoring the signal fluctuation and allowing the OOK FSO system to function with a constant threshold level will result in an increase in detection inaccuracy.

Because of the background noise, dark current dominates the detection of weak signals in FSO transmission. FSO is encountering significant hurdles in limiting the presence of undesired signal (noise) in the receiver. This is because the laser beam is transmitted straight through the air, with varying contributions from atmospheric effects (pie cite). As a result, the optimum receiver design must condense the presence of noise.

In the past, substantial research on optical communication in free space has been conducted in optical technology. Compared to other mediums, such as microwave, radio frequency, and others, this technology is particularly alluring and promising. As end-user demand for wireless communication increases in terms of speed, data capacity, and number of users, the free space optical system is the optimal solution. Nonetheless, there is still need for improvement in order to create a reliable and efficient performance system.

Reported in [15,16,17], this researcher has developed RoFSO system based on BCH and RS coded BPSK OFDM for 5G applications in smart cities. It applies the hybrid system using radio frequency and free space optical communication. The system embedded with OFDM coded. However, it cost complicated over the system and involve very complex development if convert in real implementation. There also reported in [20] some researcher explores in Deep Learning (DL) for improving performance of OOK Modulation Over FSO turbulent channels. It using different models of DL over different strength FSO turbulent channels, without the need for prior knowledge of the parameters of the channel. The weakness about this system it will requires very large amount of data in order to perform better than other techniques. It is extremely expensive to train due to complex data models. Moreover, deep learning requires expensive GPUs and hundreds of machines. This increases cost to the users. Meanwhile reported in [19], this research explains the performance evaluation and enhancement can be increase by using modified OOK based IM/DD techniques for hybrid fiber/FSO communication over WDM-PON systems. In this research the system will uses the modified OOK based on IM/DD to implement adaptive and electrical SNRs detection thresholds. Even though improve the performance but will involve complex process and it is computational expensive. Therefore, is not appropriate for real-time applications.

Therefore, based on prior researcher work linked to this study, it discovered that no research in ASK for OOK employing dual carrier with subtraction signal at receiver to establish a unique threshold level set to 0 amplitude has been undertaken. It can regulate and compress the presence of noise by integrating the balancing receiver. It was anticipated that a simple and inexpensive procedure capable of increasing received power, receiver sensitivity, and decreasing bit error rate would be used.

There a lot research has been carried out to overcome this problem. In this paper, we focus on development novel modulation technique with hybrid with balance receiver in order to improve signal transmission and suppress the noise at receiver. Conventional amplitude shift keying (ASK) that is on off keying (OOK) modulation will be compare with novel DTBR.

2. DTBR SYSTEM MODEL

The development of DTBR is consists of two main parts that are transmitter and receiver. For the transmitter part have two main components that are laser source and inverter data. It will use two transmitters where the second transmitter will put the inverter. In other words, the firs transmitter will carry original signal and second transmitter will carry an inverted signal. Both of signal is come from same source. The second part is receiver which consists of two main components as well that are balance receiver and subtractor. In detection signal at receiver part, the output from balance receiver 1 and balance receiver 2 will then subtracted to produce final out. We also assume that the receive signal is perfectly synchronous detect at receiver with no delay condition. The concept of DTBR hybrid with balance receiver for threshold process is illustrated as shown in Figure 3.

In this DTBR technique it is assumed that the channel is a zero-mean wide-sense stationary Gaussian process and that the receiver processing circuits, except for the threshold device, are linear. Meanwhile for the case linear-processing receiver circuit with a binary signal plus noise at the input, the sample output can be denoted as

$$r_o = x_o + n_o \qquad (1)$$

where r_o is the received signal, x_o is a signal being sent whether bit '1' or '0' and n_o is represented Addictive White Gaussian Noise (AWGN) with zero mean Gaussian random variable ($\mu = 0, \sigma_N^2 = \frac{N}{2}$).

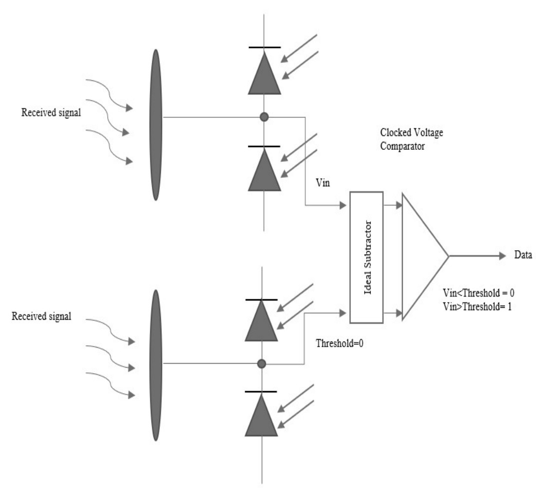


Figure 3. Receiver design for proposed DTBR concept in FSO communication

Nevertheless, the received signal for DTBR technique from photodetector 1 and photodetector 2 respectively as shown in Figure 3 which can be denoted as:

$$r_1 = x_1 + n_1 \qquad (2)$$

and

$$r_2 = x_2 + n_2 = \bar{s_1} + n_2 \qquad (3)$$

where $s_2 = \bar{s_1}$ which $\bar{s_1}$ mean complements of s_1 , the x_1 and x_2 are the signal transmitted and n_1 and n_2 are zero mean Gaussian random variable. r_o is an output signal after via the subtraction. The output after subtraction can be derived as:

$$r_o = r_1 + r_2 \qquad (4)$$

Substitute the Equation 2 and Equation 3 into Equation 4 will produce the output

$$\begin{aligned} r_o &= (x_1 + n_1) - (\overline{x_1} + n_2) \\ r_o &= x_1 - \overline{x_1} + n_1 - n_2 \\ r_o &= x + n \qquad (5) \end{aligned}$$

where the $x = x_1 - \overline{x_1}$ and $n = n_1 - n_2$. The overall process of binary detection for DTBR technique can be denoted in Table 1.

Table 1: Binary detection for DTBR technique at receiver

Transmitter (Tx)		FSO Channel	Receiver (Rx)		Subtraction process	
Sending bit			Received bit		Rx1-Rx2	
Tx1	1	Atmospheric turbulence	Rx1	1	Bit '1'	1
	0			0		
Tx2 (Inverted signal)	0		Rx2	0	Bit '0'	-1
	1			1		

3. GAMMA-GAMMA DISTRIBUTION

The Gamma-Gamma Distribution is preferred for the weak to strong regime. It is commonly used to analyze the effect of turbulence. It can predict the low intensity to high intensity for gamma-gamma. The modulation between the small-scale intensity y and the large-scale intensity x [7]:

$$I = xy \qquad (6)$$

where x and y are assumed to be gamma distributed and statistically independent. A conditional PDF for the intensity is given by the small-scale intensity, which is assumed to have a fluctuating mean that is smeared, or modulated, by the distribution of the large-scale fluctuations. The unconditional PDF for the intensity is a doubly stochastic process and is obtained by taking the expected value of the unconditional PDF, which results in the GG distribution [8]:

$$p_I(I) = \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{(\alpha+\beta)}{2}-1} K_{\alpha-\beta}\left(2\sqrt{\alpha\beta I}\right)$$

For I>0

(7)

where I is the normalized intensity, $\Gamma_{(x)}$ is the gamma function, and $K_\mu(x)$ is the modified Bessel function of the second kind. α and β are the parameters of the PDF, which represent the effective numbers of large- and small-scale scatterers, respectively. They are related to the scintillation index by calculating the second moment of the Gamma-Gamma distributed intensity:

$$\langle I^2 \rangle = \left(1 + \frac{1}{\alpha}\right)\left(1 + \frac{1}{\beta}\right) \qquad (8)$$

4. FLUX VARIENCE

To analyse the intensity of fluctuation, the flux variance will be used. It is related with the rate of flow of some quantity at atmosphere. The flux variance of the intensity fluctuations at the detector plane that calculated for the collecting lens with normalized radius Ω_G is valid for all atmospheric conditions as given in [9]:

$$\sigma^2_{flux}(L + L_f, \Omega_G) = exp[\sigma^2_{lnx}(L + L_f, \Omega_G) + \sigma^2_{lny}(L + L_f, \Omega_G)] - 1 \qquad (9)$$

where $\sigma^2_{\ln x}$ is the flux variance associated with large-scale fluctuations.

The effect of aperture averaging can be describing as when the receiving aperture is larger than a spatial scale size that produces the intensity fluctuations, the receiver will average the fluctuations over the aperture and the scintillation will be less compared to scintillation measured with a point receiver [10]. It has been shown that aperture averaging causes a shift of the relative spatial frequency content of the intensity spectrum toward lower frequencies, since the fastest fluctuations caused by small-scale sizes average out. Hence, the scintillation measured by a receiving aperture is produced by scale sizes larger than the aperture. The obvious advantage of increasing the aperture size is collecting more light. However, as the aperture size exceeds several times the coherence length of incident light on it, the scintillation index gets reduced, a phenomenon known as aperture averaging [11].

In strong turbulence, there is two-scale behaviour in the intensity flux variance obtained by a finite size receiving aperture. A sharp decrease in scintillation is observed for increasing aperture sizes up to the coherence scale, ρ_o, after which there is a levelling effect, followed by a second decrease in the intensity flux variance when the aperture exceeds the scattering disk $L/\kappa\rho_o$. The levelling effect arises since medium-scale sizes are inefficient in producing scintillation in strong turbulence. Hence, if a receiving aperture is larger than ρ_o in strong turbulence, the small-scale scintillation is mostly averaged out. This should affect the PDF of the intensity fluctuations since existing models, developed for point receivers, are obtained by modulating the small- and large-scale distributions. Therefore, in this thesis we use the Gamma-Gamma distribution and suitable for all fluctuation regime [12].

The log intensity due to large scale eddies is given as;

$$\sigma^2_{\ln x}\left(L+L_f,\Omega_G\right)=0.49\sigma_R^2\left(\frac{\Omega_G-\Lambda_e}{\Omega_G+\Lambda_e}\right)^2 XR\left[\frac{\eta_x}{1+0.4\eta_x\dfrac{(1+\Theta_e)}{(\Lambda_e+\Omega_G)}}\right]^{7/6}$$

(10)

where

$$R=\frac{1}{3}-\left(\frac{1}{2}\right)(1-\Theta_e)+\left(\frac{1}{5}\right)(1-\Theta_e)^2$$

The quantity η_x is the normalized large-scale cut-off frequency determined by the asymptotic behaviour of $\sigma^2_{\ln x}$ in weak turbulence and saturation regime:

$$\eta_x=\frac{R^{-6/7}\left(\dfrac{\sigma_B}{\sigma_R}\right)^{12/7}}{1+0.56\sigma_B^{12/5}} \qquad (11)$$

Meanwhile log intensity due to small scale eddies is given as;

$$\sigma^2_{\ln y}\left(L+L_f,\Omega_G\right)=\frac{1.27\sigma_R^2\eta_y^{-5/6}}{1+0.4\dfrac{\eta_y}{(\Lambda_1+\Omega_G)}}$$

(12)

where the corresponding cut-off frequency is

$$\eta_y=3\left(\frac{\sigma_R}{\sigma_B}\right)^{12/5}\left(1+0.69\sigma_B^{12/5}\right)$$

(13)

5. BIT ERROR RATE

The general expression for the bit error probability of any binary communication is given [13,14]

$$P_e=P(1)\int_{-\infty}^{V_T}P(0|1)dI+P(0)\int_{V_T}^{\infty}P(1|0)dI$$

(14)

When determine the BER performance under the turbulence effect, it has to consider the whole probability of error. Since the signal of noise ratio using the mean value, therefore it will involve the integral of BER to obtain the mean of BER. The probability error of DDM performance in the presence of turbulence with using the Gamma-Gamma distribution can be written as:

$$\Pr(E)=\langle BER\rangle=\frac{1}{2}\int_0^{\infty}p_I(I)erfc\left(\sqrt{\left\langle\frac{E_b}{N_o}\right\rangle I}\right)dI$$

(15)

where $p_I(I)$ is a gamma-gamma distribution and the $\left\langle\dfrac{E_b}{N_o}\right\rangle=\langle SNRP\rangle$.

When aperture averaging effects are considered, parameters α and β of the gamma-gamma PDF are defined as

$$\alpha=\frac{1}{\exp\left[\sigma^2_{\ln X}\left(L+L_f,\Omega_G\right)\right]-1}$$

(16)

$$\beta=\frac{1}{\exp\left[\sigma^2_{\ln Y}\left(L+L_f,\Omega_G\right)\right]-1}$$

(17)

where $\sigma^2_{\ln x}(L+L_f,\Omega_G)$ and $\sigma^2_{\ln y}(L+L_f,\Omega_G)$ are relate to large- and small-scale log intensity variances obtained in Equation 10 and Equation 12 respectively.

Journal of Theoretical and Applied Information Technology
31st January 2024. Vol.102. No 2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

6. SIMULATIONS SETUP

The Optisystem software was used to simulate the performance of the DTBR approach. The topology of the DTBR setup for simulation analysis is depicted in Figure 4. The laser source employed at the transmitter is a Continuous Wave (CW) laser with a transmit power of 0 dBm. The wavelength of 1550nm was chosen because it performs better than 850nm. Pseudo-Random Bit Sequence (PRBS) with Non-Return Zero (NRZ) as a modulation format was used to generate the data. The electrical signal will then be modulated into an optical signal by an external modulator, the Mach-Zehnder Modulator (MZM), prior to transmission. There will be two transmitters used: one for original data and one for inverting data.

In medium part, the FSO component will be used. The propagation range is set at 1 km and the attenuation of atmospheric is set to 0 dB/km for condition without presence of turbulence. If presence of turbulence, the attenuation will set in various value according to calculation via theoretical. For the intensity scintillation is set at 100 x 10^{-15} $m^{-2/3}$ for strong turbulence condition and for weak turbulence 1 x 10^{-15} $m^{-2/3}$. Under geometrical loss factors, the transmitter aperture and receiver aperture are set 2.5cm and 8cm respectively. Meanwhile the beam divergence is pick at 1 mrad and other parameters such as transmitter loss, receiver loss, additional loss and propagation delay are remaining in default value. The noise that generated at receiver were set at random and the dark current value at 10nA with responsivity 1 A/W and thermal noise 100 x 10-24 W/Hz. The performance of the system can be evaluated through BER analyzer, oscilloscope visualizer and eye patterns.

At the receiver, it is assumed that none of the signals that were received had any delay before being detected by the balance receivers 1 and 2. Both of the receivers' balances are equipped with two photodetectors each. It is anticipated that the noise will be compressed by the balancing receiver, and the photodetector will transform signals from optical to electrical. The signal from the filter will be applied to the output of the balance receiver, and the data will then be sent to the subtraction component section. Output from subtraction procedure is the ultimate output of the DTBR technology.

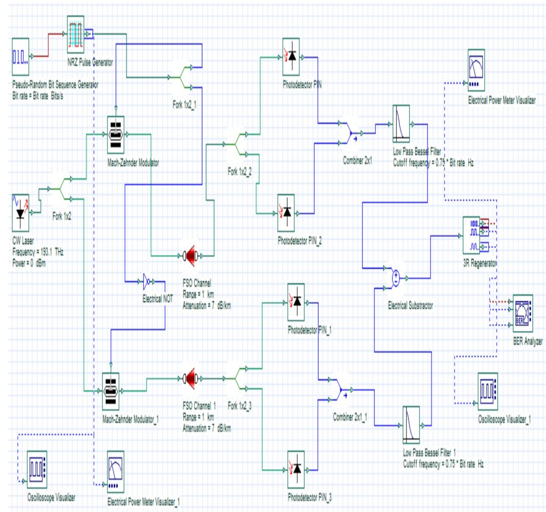


Figure 4: Setup simulation for DTBR

7. RESULT AND DISCUSSION

The results are generate using Optisystem simulator. The parameter use for analysis are wavelength 1550nm, power transmit= 0 dBm, collecting lens W_G = 0.01, spot beam at transmitter (z=0) and distance = 1km.

The Figure 5 (a) and (b) shows the performance of eye pattern and oscilloscope result without presence of turbulence. The opening of eye pattern is high it indicates the performance of the system a good and the minimum BER usually below than 10^{-9}. Otherwise, if the opening of eye pattern is low indicate that the system turns to poor performance and in worst condition there is no shape of eye pattern which represent the signal is totally loss. Meanwhile for oscilloscope result, generally shows the three patterns of signal which is consist of signal and noise power. The blue line represents the signal plus noise power meanwhile the red line represents the only signal power and the green line represent only noise power. The opening of eye pattern is high which indicate the performance of system is good and this condition can be viewed effectively in oscilloscope result where the signal power (red line) is high if compare with the noise power (green line). This shows that the level of noise power is still low and allow the detector to receive the signal power with high rate.

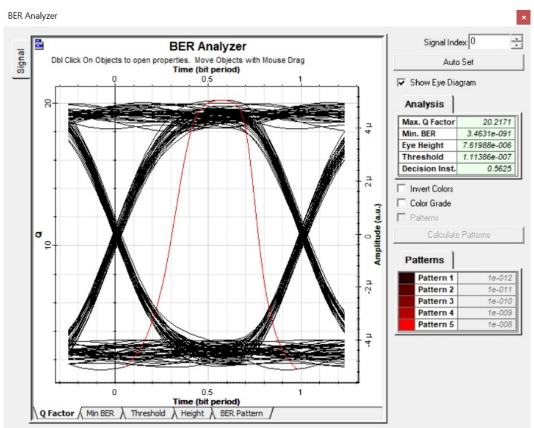
Figure 6 (a) and (b) shows the performance of eye pattern and oscilloscope result due to presence of turbulence at Cn2=1x10^{-15} $m^{-2/3}$. The eye opening seems to close with the eye height drop. Meanwhile in oscilloscope result pattern the gap between signal power and noise power are

Journal of Theoretical and Applied Information Technology
31st January 2024. Vol.102. No 2

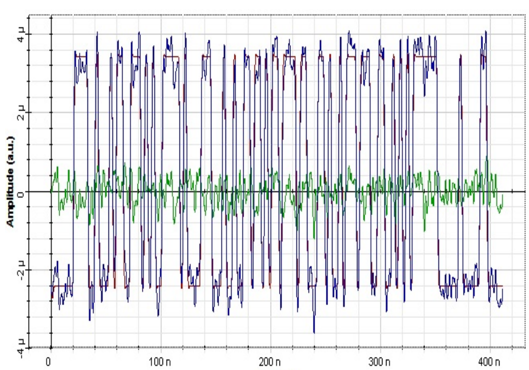
ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

becoming close. This indicates the performance is deteriorating where the noise power is increased but the signal power is decreasing.

For the worst condition as shown in Figure 7 (a) and (b) for the heavy turbulence at $Cn^2 = 100 \times 10^{-15}$ $m^{-2/3}$. At this stage there is no eye-opening pattern and usually the minimum BER is at value 1 which represent the high error. For the noise power pattern of oscilloscope results show that the it surpasses the signal power. This indicates that the level of the signal power is very weak and the noise power dominates the overall signal. Here also show that at this point the signal plus noise (blue line) shape pattern turn to similar to noise power.

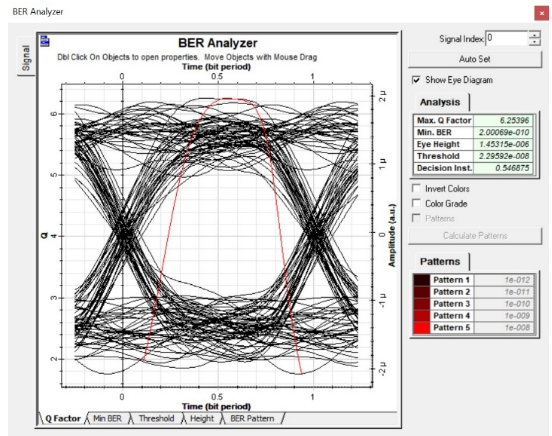


(a)

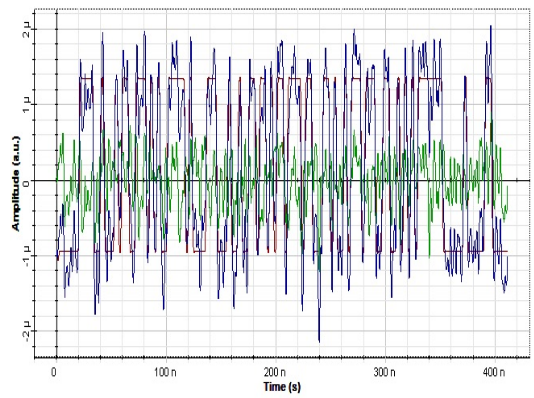


(b)

Figure 5. (a) and (b): Performance of eye pattern and signal power with noise power without presence of turbulence with parameter simulation L = 1km, θ=1mrad, Pt=0dBm, λ=1550nm, Bit rate =155Mbps

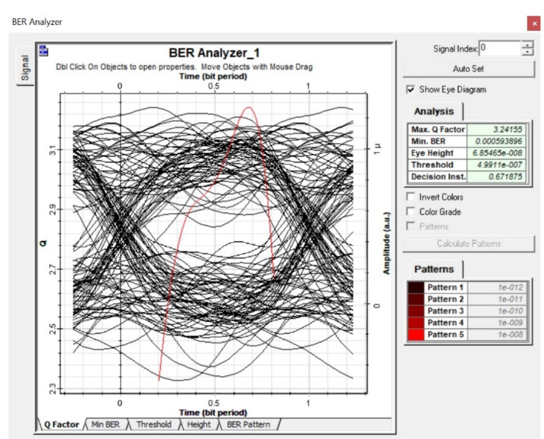


(a)

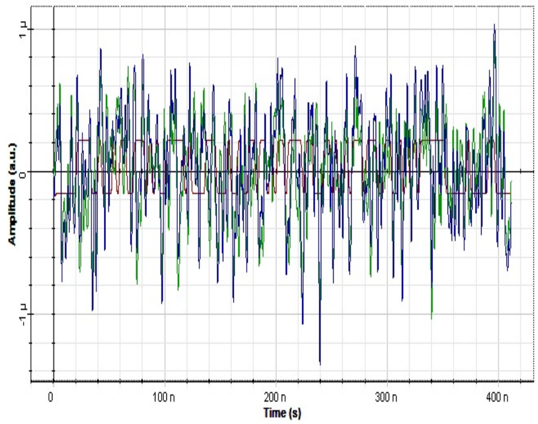


(b)

Figure 6. (a) and (b): Performance of eye pattern and signal power with noise power with presence of turbulence with parameter simulation L = 1km, θ=1mrad, Pt=0dBm, λ=1550nm, Bit rate =155Mbps, $Cn^2=1x10^{-15}$ $m^{-2/3}$



(a)



(b)

Figure 7. (a) and (b): Performance of eye pattern and signal power with noise power with presence of heavy turbulence effect with parameter simulation L = 1km, θ=1mrad, Pt=0dBm, λ=1550nm, Bit rate =155Mbps, 100 x 10^{-15} $m^{-2/3}$

In bit rate analysis, we simulated the data bit rate from 155Mbps until 10Gbps. Here we fix the diameter lens at D= 8cm with beam divergence value 1mrad. The turbulence is set at $1x10^{-13}$ $m^{-2/3}$ under strong turbulence region. Figure 8 shows the simulation result for BER versus bit rate under strong turbulence condition. The comparison is between conventional ASK and DTBR along with eye pattern performance. At higher bit rate of 10 Gbps, it can be seen that DTBR can support the transmission where the BER is at 5.91 x 10^{-11} as compared to conventional ASK surpass the minimum acceptable BER where at 2.77x 10^{-4}. This can indicate as well in eye diagram shape where the opening eye for conventional ASK is lower. In other word the DTBR system can improve the error bit and at same time can support the high-speed data rate transmission. With this, FSO technology can fulfill the high demand of nowadays consumer which want the faster technology in data transmission.

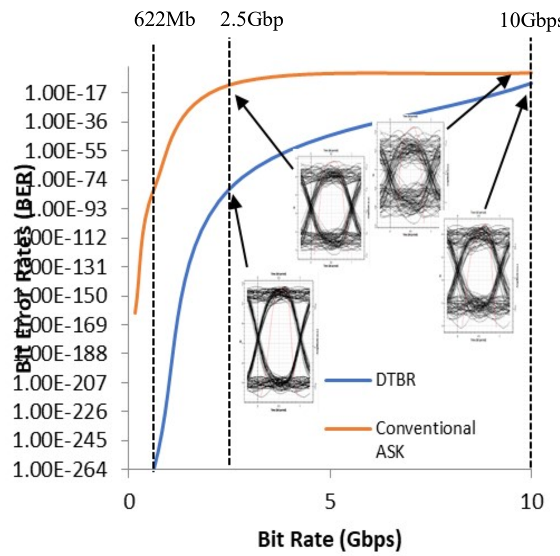


Figure 8. BER versus data bit rate under strong turbulence condition

Figure 9 shows the simulation result for comparison BER versus different STM level bit rate. The Synchronous Transport Module (STM) is a fiber optic network standard for SDH (Synchronous Digital Hierarchy). From the result, at minimum acceptance BER (straight red line) the lowest bit rate which is STM-1 (155Mbps) shows the performance better at higher attenuation which is approximately at 15 dB/km. Meanwhile conventional ASK only able to reach 12 dB/km. At higher bit rate which is STM-16(2.5Gbps), the DTBR can support attenuation closed to 6 dB/km but conventional ASK only at 3 dB/km. Both of these result shows that improvement of DTBR about 25% as compared to conventional ASK. It indicates that this new approach can perform well either at low bit and higher bit rate.

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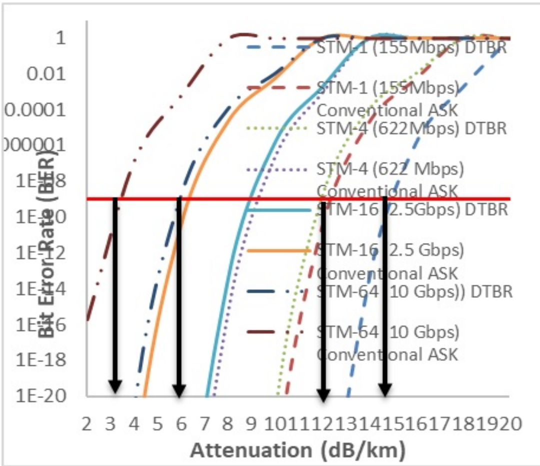

Figure 9. Comparison BER versus different STM level bit rate

Figure 10 shows the comparison BER versus attenuation for different range propagation under strong atmospheric turbulence. In the short distance propagation for 1km, the performance BER at minimum acceptable 10^{-9} shows both approach able to support attenuation above 10 dB/km where DTBR and conventional ASK at 15dB/km and 12 dB/km respectively. This gives improvement approximately 25%. However, at long distance for 2km, both of approach is at 5dB/km and 3 dB/km respectively which still DTBR perform better. From this finding, it shows that the ability of DTBR can offer FSO system to transmit more distance coverage with able to perform well at high attenuation effect.

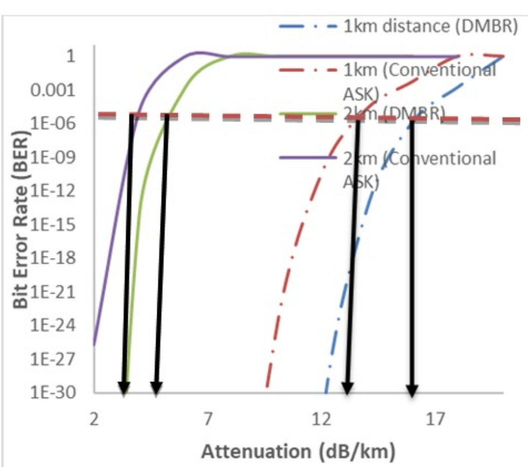

Figure 10. Comparison BER versus attenuation for different range propagation

8. CONCLUSIONS

A unique modulation DTBR approach has improve the threshold issue in traditional ASK and lessen the influence of noise at the receiver. Balanced detection enables the utilisation of the whole incoming signal strength for detection, while discarding photons that carry no relevant information. Balanced detection gives a larger optical power dynamic range and longer reaches than single-ended detection. As summary analysis related bit rate performance when presence of turbulence the FSO still able to support transmission. In term of bit rate performance, 25% improvement can be achieved. It as well shows that DTBR can operate at high data bit rate (STM64) 2.5 Gbps. For the distance performance, 25% of improvement as well dominated by DTBR. This will contribute great advantage for FSO to expand the distance transmission even having high atmospheric attenuation. There, the receiver sensitivity can be improved.

9. ACKNOWLEDGEMENT

The authors thank Ministry of Higher Education Malaysia for the Fundamental Research Grant Scheme (Grant no. FRGS/1/2019/TK04/UNIMAS/02/2).

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