Bit Error Rate performance analysis for Free Space Optic communication

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Abstract. This paper discusses the comparison of 4 modulation in Free Space Optic communication namely; Pulse Position Modulation (PPM), Pulse Amplitude Modulation (PAM), and On Off Keying Modulation (OOK). By Utilizing a light source with a length of 1550 nm, a simulation measured by Bit Error-Rate using Signal-to-Noise Ratio (SNR) in several distance. In this research, researchers used a quantitative approach by MATLAB simulation and using correlational studies to compare BER, SNR, distance and visibility. The results show that PPM is the most effective modulation in comparison with others.

1. Introduction

FSO technology utilize atmospheric channel as a propagating medium whose properties are random function of space and time [1]. There are many factors that cause attenuation in the optical signal like clouds, snow, haze, fog, rain, etc. In addition, link distance and pathloss are another factor that affect FSO communication. There are several channel models to estimate optical attenuation through fog using visibility as an input parameter [2]. Kim is one of the model that represent analysis of optical attenuation.

An implementation of FSO will be very helpful to a country due to information is an essential need for everyone to fulfill their needs. The research nowadays show that if the implementation of public information is running well, the effective and reliable governance will be realized. In addition, digital transformation is very necessary to improve the performance of government at the central and regional levels. So, the satisfaction people index on the city will be increased [3].

In a previous study that discussed BER, Power and Bandwidth performance by using several quadrature Phase Shift Keying (QPSK) modulation techniques, Binary Phase Shift Keying (BPSK), Differential Phase Shift Keying (DPSK), On-Off Keying (OOK) Return Zero (RZ) - Non Return Zero (NRZ), Pulse Amplitude Modulation (PAM) and Pulse Position Modulation (PPM). The research shows that L-PPM modulation technique is the best modulation to improve power efficiency in FSO [4]. In the other hands, M-PAM is usually used in communication system to increase bandwidth efficiency on FSO, where M is the data encoded as pulses that are sent [5].

In this research, a measurements will be carried out to determine the SNR variation and value of BER against distance with various modulation techniques. One of the challenge in implementing a FSO technology is attenuation that can limits the optical propagation path. Besides that, it affect signal quality
and communication services. ITU-R model parameters is usually used to provides rainfall rate statistics that are closer to the value measured but surface rain gauge [6].

2. System models and channels

Various factors that usually called attenuation will affect BER when sending data in FSO communication [7]. To find out the data transmission changes in Bit Error Rate (BER) value, it can be done by measuring the power level on the receiver side with the following equation:

\[
Pr = Pt \cdot \tau t \cdot D^2 / (\theta L^2) \cdot 10^{\left( [\frac{L}{g1863}] - \gamma(\lambda) \right)(L/10)}
\]  

with \( Pr \) representing the efficiency of information delivery and \( Pt \) representing the efficiency of reception in optics, while \( D \) represents receiver diameter and \( \theta \) is transmission angle divergence.

One of the factor that can affect FSO communication atmospheric attenuation is scattering factor. Scattering occurs when the transmission of light information collides with gas molecules or aerosols [8], so that the information signal will spread. In its application, FSO has a channel model one of them is the Kim model which has an equation:

\[
\beta(\lambda) = \frac{3.91}{V} \cdot \left( \frac{\lambda}{550} \right)^{-\delta}
\]  

where \( \lambda \) is the wavelength for FSO and \( V \) is the visibility in (Km) where visibility is the visibility of an object.

The visibility category for Kim models is stated in the following table:

| \( \delta \) | \( V \) |
|-----------|--------|
| 1.6       | \( V > 50 \) km |
| 1.3       | \( 6 \) km < \( V < 50 \) km |
| 0.16      | \( 1 \) km < \( V < 6 \) km |
| 0.34      | \( 0.5 \) km < \( V < 1 \) km |
| -0.5      | \( V < 0.5 \) km |

In this paper visibility is measured up to 6 km, the attenuation of syntax is caused by light turbulence caused by variations in the refractive index of temperature, pressure and particles in the atmosphere [9]. With the following equation:

\[
[\sigma x]^{2} = 1.23 \cdot C_n^2 \cdot 2 \cdot k \cdot (7/6) \cdot L \cdot (11/6)
\]

Where \( \sigma x \) is a variation of scintillation, \( C_n^2 \) is a refractive index structure parameter, \( k \) is \( 2/\lambda \) and \( L \) (km) is a distance from transmitter to receiver. Scintillation attenuation can be calculated by the following equation:

\[
\gamma \text{ scintillation} = \sqrt{\sigma x^2}
\]
Table 2. Free space optic link parameter.

| Parameter              | Value               |
|------------------------|---------------------|
| Wavelength             | 1550 nm             |
| Link Distance          | 0 – 2 km            |
| Power Transmitter      | 0.1 W               |
| Diameter of Detector   | $10^{-5}$           |
| Beam Divergence        | $10^{-3}$           |
| Electron Charge        | $1.6 \times 10^{-19}$ |
| Bandwidth              | 1 GHz               |
| Responsivity           | 1.68                |
| Dark Current           | $10^{-8}$           |
| Temperature            | 298K                |
| Boltzman Constanta    | $1.38 \times 10^{-23}$ |
| Noise Figure           | 1                   |
| Load Resistor          | 1000                |
| Visibility             | 0 – 2 km            |

In this paper PPM, PAM, and OOK modulation will be compared. There is an advantage in PPM and OOK Modulation in the form of high efficiency of the power used but it has disadvantages in bandwidth. Whereas in PAM modulation, it has efficiency of bandwidth. But PAM modulation requires a lot of power [10]. This research also displays the observational data about the correlation between BER and link distance. Based on the testing that has been done, the SNR value will be the reference of the BER equation while the Photodetector PIN is used as the receiving device.

$\text{SNR} = \frac{(I_p \cdot s^2)}{(2qB(I_p + ID) + 4KbTBF)}$ (5)

where $I_p$ can be calculated from $I_p = Pr R$, $B$ is the signal bandwidth, $q$ is the unit of electron value, $ID$ is the dark current value, $T$ is representing the temperature value in the photodetector. $F_n$ is a noise figure value which is equal to 1 and $RL$ is the resistor load on photodetector.

BER (Bit Error Rate) is a unit of error sending data bits per total data bits sent. The BER has a unit ratio, the BER value depends on the SNR value and the use of the chosen modulation technique. In comparison, BER is more often used by researchers, technicians, industrial workers due to its simplicity [12]. PPM is a modulation where the position of the carrier signal pulses varies with the modulating signal. This modulation has the same signal amplitude and width. In this modulation, each pulse on the laser represents one or more bits of information based on their position to time. In PPM, several bits are sent at a time. The ppm block encoding is done by converting each value of "K" bits to $L = 2^K$ [13].

$PPM = \frac{1}{2} erf c \left( \frac{1}{2\sqrt{2}} \sqrt{SNR} \frac{L}{2 \log 2 L} \right)$ (6)

PAM (Pulse Amplitude Modulation) is a modulation where the amplitude of the signal is varied based on the modulating signal. The pulse position and width of the modulated signal are fixed.

$PAM = \frac{1}{2} erf c \left( \frac{\sqrt{SNR \log 2 M}}{2\sqrt{2}} \left( \frac{M}{M - 1} \right) \right)$ (7)
OOK-NRZ (On-Off Keying No Return Zero) is a type of modulation that is considered as on or sending data and if the value is 0, it’s considered off or not sending data. In full wave OOK-NRZ, it has a value equal to 1. In addition, OOK-NRZ has greater bandwidth and greater power as well.

\[
OOK - NRZ = \frac{1}{2}\text{erfc}\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right)
\]

(8)

OOK-RZ Modulation (On-Off Keying Return Zero) OOK-RZ (On-Off Keying Return Zero) is a type of modulation that only sends half wave. So it has less bandwidth than OOK-NRZ, but has lower power efficiency. The equation for OOK-RZ is:

\[
\frac{1}{2}\text{erfc}\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right)
\]

(9)

3. Results and discussion

![Figure 2. BER to SNR with various modulation.](image)

In Figure 2 that includes Signal-to-Noise ratio and Bit Error Rate axis to identify the most efficient modulation that can be used in Free Space Optic Channel. The Figure Show that the most efficient modulation is the one who has the least value in BER and has the most value in SNR. PPM Modulation has the least BER value while PAM modulation has the biggest value of BER As the BER value increasing the quality of an information in a signal is decreasing.

![Figure 3. BER to visibility with various modulation.](image)
In Figure 3 beside obtained the result of comparison in several modulation, there is a ratio BER to Visibility. In addition, PPM is also has the best performance according to the figure. Visibility is the distance how far the signal can be transmitted without interference or obstacles such as fog, rain droplets, aerosols, fog, haze and other particle.

![Figure 4. BER to length analysis with various modulation.](image)

In Figure 4 beside obtained the result of comparison in several modulation, there is a ratio BER to Visibility. In addition, PPM is also has the best performance according to the figure because it can sent one or more bits information for each pulse of the laser. OOK-RZ modulation is the next due to its efficiency low power. OOK-NRZ is still more efficient than PAM modulation, even OOK-NRZ modulation consume more power and have greater bandwidth thank RZ-OOK modulation.

### Table 3. Bit error rate in various modulation.

| Distance | PPM  | OOK-RZ | OOK-NRZ | PAM  |
|----------|------|--------|----------|------|
| 0.4 km   | $10^{-7}$ | $10^{-3}$ | $10^{-2}$ | $10^{-1}$ |
| 0.6 km   | 0.017 | 0.1    | 0.14     | 0.25  |
| 1 km     | 0.28  | 0.34   | 0.352    | 0.41  |
| 1.4 km   | 0.36  | 0.42   | 0.43     | 0.451 |
| 1.6 km   | 0.45  | 0.44   | 0.45     | 0.47  |

In Table 3 the result show that in several distances below 2 km due to optical communication standard. PPM modulation has the least BER value, then OOK-RZ Modulation, OOK-NRZ modulation and the last is PAM Modulation. The longer the link distance of FSO Channel the bigger the value of BER each modulation.

4. Conclusion

Analysis and simulation conducted in this paper show the four modulation experiments and the comparison of BER, SNR, distance link and visibility. It is proved that the most efficient modulation is PPM compared to OOK-RZ, OOK-NRZ, and PAM. The reason is because each pulse on the laser represents one or more bits of information based on their position to time. RZ-OOK modulation is more efficient than the NRZ-OOK modulation due lower power efficiency. The distance of this simulation used 1-2 Km due to the standard of optical communication free space optic implementation.
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