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INVESTIGATION OF NON CHIRPED NRZ, CHIRPED NRZ AND ALTERNATE-CHIRPED NRZ MODULATION TECHNIQUES FOR FREE SPACE OPTIC (FSO) SYSTEMS

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ABSTRACT

Free Space Optics (FSO) is the technology where transmission occurs through optical waveform that contains data transformed at the transmitter from electrical signal. Since the transmission medium of FSO is atmosphere, atmospheric scattering is the major cause for interruption of FSO link. Non return zero (NRZ) modulation is the dominant modulation scheme employed in commercial terrestrial Free Space Optic (FSO) communication systems. This research are required to investigate three viable modulation techniques; non-chirped NRZ, chirped NRZ, and alternate-chirped NRZ at 10 Gb/s and 40 Gb/s data rate. The 1550 nm of continuous wave (CW) laser is modulated with three different modulation formats over 1 km of FSO channel. The signal is propagated at different attenuation value based on Malaysia weather conditions. In this paper we have successfully compared the three modulation techniques in FSO system due to the Malaysia weather and the performance is accessed at bit error rate (BER) of 1×10^{-9}. The presented simulation of these three modulation shows that alternate-chirped NRZ has slightly better performance compared to the non-chirped NRZ and chirped NRZ modulation format at clear weather, haze, light rain, medium rain and heavy rain. We believe that, this system is an alternative for the future optical wireless network that has a potential to be installed in the urban and sub-urban area.

Keywords: free space optic, non return zero, chirping, modulation.

INTRODUCTION

Free space Optic (FSO) is a significant building block for wide area space networks, supporting mobile users, high speed data services for small satellite terminals and serving as a backbone network for high speed trunking (Chan, 1999). FSO is one of the most promising candidates for future broadband communications, it offers a high transmission rates. Besides a high transmission rate, it has some advantages if we compare with radio frequency (RF) wireless communication and conventional wired transmission (Zin, 2010). FSO links offer a high security due to beam confinement within a very narrow area, consume a relatively low power, and are less sensitive to the electromagnetic interference (Arnon, 2003). Non return zero (NRZ) modulation is the dominant modulation scheme employed in commercial terrestrial Free Space Optic (FSO) communication systems. This is primarily due to its simplicity and resilience to the innate nonlinearities of the laser and the external modulator (Liu, 2008).

At the transmitter side, the pre-chirping of optical pulses enables an improvement of transmission performance of the system. Therein, the pre-chirp can be implemented using passive components such as fiber piece, optical filter or active components such as Mach-Zehnder Modulation (MZM) and phase modulator. Although the implementation of the pre-chirp will cause a broadening of the signal spectrum, but the pre-chirp can reduce the tolerance of residual dispersion and narrowband filtering. Accordingly, the amount of the pre-chirp and the method of its implementation have to be carefully chosen in order to meet desirable system requirements (Hodzig, 2004).

In this research, we have successfully compared and investigated three types of NRZ modulation which are non chirped NRZ, chirped NRZ, and alternate-chirped NRZ for FSO network application. Indicator of the performance parameters of this project is assessed at bit error rate (BER) of 1×10^{-9}.

FREE SPACE OPTIC

Introduction to free space optic

Free space optical communication is a broadband access technology that offers very high data rate point-to-point links. FSO is very interesting topic to research community due to its low bit error rate, huge bandwidth, it easy deployment and license free operation. These excellence of FSO communications are very attractive for applications in electronic commerce, free web browsing, data library access, work-sharing capabilities, enterprise networking real time medical imaging transfer and high speed interplanetary links (Rajbhandari, 2011). In tropical regions, with the present of fog, heavy rain is the main problem for the unavailability of an FSO link. Rainfall

exists due to non-selective scattering which is wavelength independent. System with signal frequencies below 10 GHz is not affected by any weather condition (Willebrand, 2002).

An investigation of a wavelength division multiplexing (WDM) FSO system by a numerical expression and simulation has been investigated (Fadhil, 2013). Two kinds of parameters; external parameter and internal parameter which affected the FSO system. For external parameters, they exists caused by the variation of weather conditions. Haze and rain condition influenced the performance of FSO. However when the weather is clear, a system with data rate 2.5 Gbps and distance of 150 km has been successfully transmitted. The tradeoff between simulation parameters is shown in the simulation results which are the distance, data rate, and input power. During the clear weather the data rate of 2.5 Gbps with BER of 2.72×10^{-11} is achieved at 150 km distance. The effects of external parameter caused by the weather condition has been successfully presented in numerical expression and simulation using OptiSystem 7.0. The result of comparison on the FSO link at 850 nm, 1310 nm and 1550 nm with propagation distance of 150 km is presented. From the findings the FSO systems is hardly attenuate the performance during the heavy haze, light rain, medium rain and heavy rain when the system link is getting longer. In order to solve this problem, the shorter link range and lower data rate are required to optimize the FSO system transmission components.

In (Suriza, 2011) reported that preliminary analysis on the effect of rain in tropical environment demonstrate that heavy rain can interrupt the FSO link. The results show that attenuation model is required to represent the best tropical weather condition.

Modulation technique in FSO system

In (Rajbhandari, 2011) reported the investigation of the performance of received signal for on-off keying non-return-to zero (OOK-NRZ), pulse amplitude modulation (PAM) and subcarrier intensity modulation (SIM) based on a binary phase shift keying (BPSK) schemes under the influence of fog and turbulence for the FSO link. Since information is carried in phase of the carrier, the BPSK should in principle offer improved performance in the presence of the turbulence induced random amplitude fluctuation the experimental evaluation of the performance of different modulation schemes under the effect of atmospheric turbulence and fog for FSO communication links in a controlled laboratory test-bed was carried out. The results indicate that BPSK and OOK-NRZ modulation signalling format are more robust to fog and turbulence impairments on the FSO link, in comparison with 4-PAM.

The implantation of BPSK signalling increased the efficiency of the FSO link under fog conditions

nevertheless implies a higher receiver complexity and lower normalized gain compared with OOK-NRZ.

Atmospheric attenuation

The weather can impact the FSO system and introduced loss of the media between the transmitter and receiver of FSO link vary in time. Futhermore the rain intensity also contributed to the degradation of the laser power and reduced the FSO system performance (Willebrand, 2002). Therefore, it is important to take consideration of the weather condition in the FSO system, such as, rain and haze.

In general, there are two key factors which can impair the FSO system performance; they are weather condition and installation of the FSO hardware itself. Firstly a temporarily hardware FSO installation at site are acquired to check the attenuation performance. After the analysis of the atmospheric attenuation has been made, then the system can be permanently installed and commissioned.

Simulation setup of theVLC system

The simulation was performed using Optisystem 13 software. In this system design, the transmitter and receiver gains are set to 0 dB by assuming both of the equipment is ideal. Besides that, scintillation and miss pointing losses are not considered in this simulation work. A simple schematic diagram of the FSO simulation setup is illustrated in Figure-1.
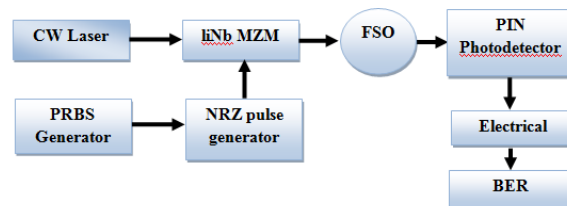

Figure-1. Simulation design of the NRZ modulation in the FSO system.

A pseudo random binary sequence (PRBS) transmits a bit sequence length of 2^{15}-1 bits by using NRZ modulation. A continuous wave (CW) laser at 1550 nm with 100 MHz line-width is externally modulated with the non chirped NRZ signals. The signal is propagated in the FSO link model under different weather condition. The main difference of the other types of modulated signals are the chirped NRZ has a sine generator and phase modulator (PM) modulator while alternate-chirped NRZ required Mach-Zehnder modulator and sine generator before the signal is transmitted.

The attenuation value is set according to five different Malaysia weather. For clear condition, the attenuation is set to 0.233 dB/km, haze is set to 2.37 dB/km, light rain is set to 6.27 dB/km, medium rain is set

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to 9.64 dB/km and 19.28 dB/km for heavy rain (Fadhil, 2013). The optical transmitter aperture is fixed at 2.5 cm and receiver aperture is varied from 12 to 23 cm for optimization. The distance of FSO propagation is varied from 900 to 1000 meter for 10 Gb/s system and from 600 to 900 meter for 40 Gb/s system.

At the receiver, the incoming signal is detected by a PIN photodetector. The dark current value is set at 10nA and the thermal noise coefficient is 1e-022 W/HZ. The performance of the system was characterized by accessing the sensitivity of BER at 1×10^{-9} against input power and distance.

The effect of optical input power for the FSO system

The simulated result in clear weather is shown in Figure-2. As can be seen from the figure, at transmission distance of 1 km, the BER decreased as the optical power input is increased. For data rate of 10 Gb/s, FSO system requires a power input less than the data rate of 40 Gb/s to send the modulated signal at 1 km of distance. Alternate-chirped NRZ has slightly better performance compared to non chirped NRZ and chirped NRZ.

The relationship between the bit error rate and optical input power in haze weather is shown in Figure-3. Haze weather has a greater attenuation than a clear weather, this causes FSO system requires optical power input greater than when it is clear. For the data rate of 10 Gb/s, the minimum optical input power is approximately 2 dBm. For the system with the data rate of 40 Gb/s needs around 1 dBm for minimum optical input power.

Rainy weather gives the big impact to the FSO system. In Malaysia, rain is divided into three conditions, namely light rain, medium rain and heavy rain. During light rain, as can be seen in Figure-4, the optical input power is required around 2 dBm for 10 Gb/s and 5 dBm for data rate of 40 Gb/s to achieve BER of 1×10^{-9}. Figure-5 shows the performance in medium rain. It required optical input power of 5.5 dBm for a data rate of 10 Gb/s while for 40 Gb/s, it needs around 8.5 dBm. The results for heavy rain are the worst condition for this analysis. As shown in Figure-6, the signals cannot be transmitted at data rate of 40 Gb/s due to the attenuation is too high. For 10 Gb/s, FSO system can only transmit the signals properly when the optical input power is more than 15 dBm.
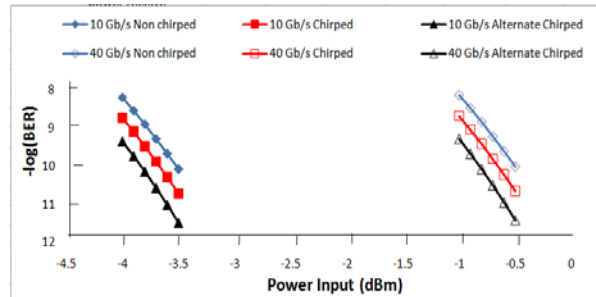

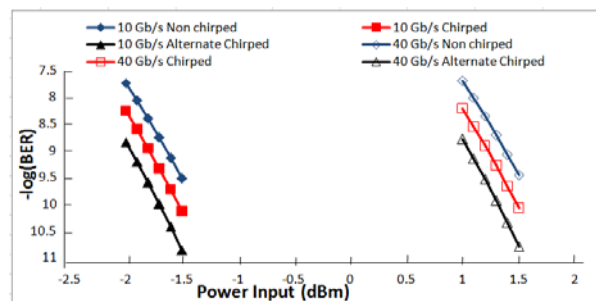**Figure-2.** The effect of optical input power during clear weather.
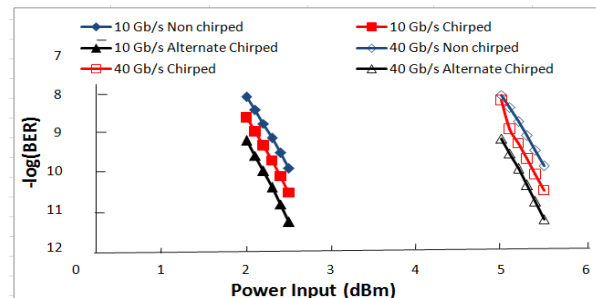

Figure-3. The effect of optical input power during haze.

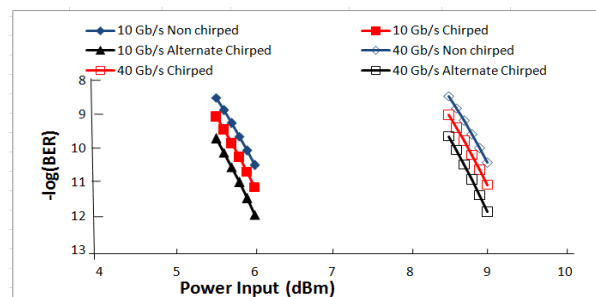**Figure-4.** The effect of optical input power during light rain.

Figure-5. The effect of optical input power during medium rain.
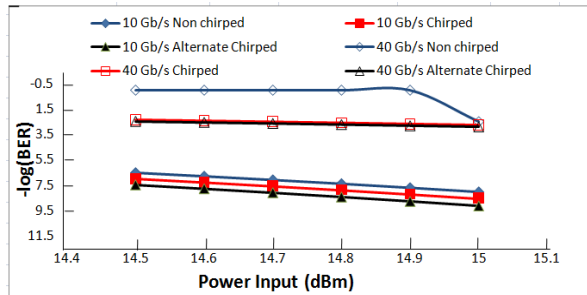
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Figure-6. The effect of optical input power during heavy rain.

The effect of distance in the FSO system

Figure-7 shows the effect of the distance in FSO system in the heavy rain weather. The BER is bigger when the propagation distance is getting longer. The data rate of 10 Gb/s has a smaller BER value compared to the data rate of 40 Gb/s. Thus, the maximum distance that can be gained for the FSO system with a data rate of 10 Gb/s is longer compared to a system with a data rate of 40 Gb/s. 10 Gb/s has a maximum length of 1 km. 40 Gb/s has a maximum length of 0.9 km, with the same input power of 15 dBm.

Medium rain weather has a longer maximum distance due to the smaller attenuation. Figure-8 shows the maximum distance that the signal can be propagated are 1.6 km and 1.4 km for 10 Gb/s and 40 Gb/s respectively.

During the light rain condition, the performance is similar to heavy rain or medium rain. The three modulation formats have a longer transmission distance at 10 Gb/s. Figure-9 shows that the data rate of 10 Gb/s has a maximum distance of 2.05 km and 40 Gb/s has 1.7 km by accessing at BER of 1×10^{-9}.
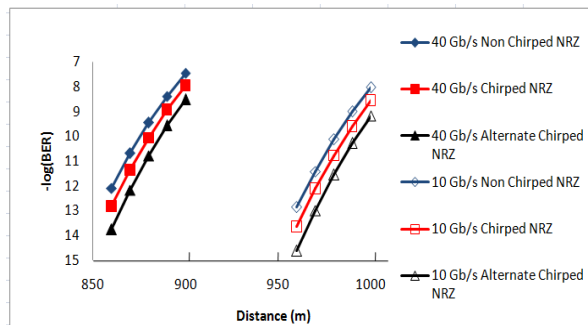

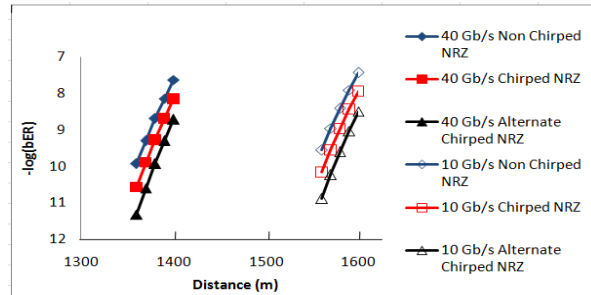**Figure-7.** The effect of distance in heavy rain weather.

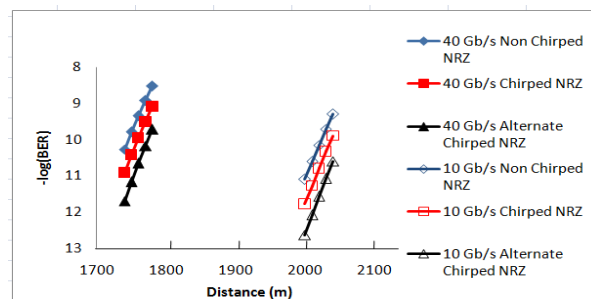**Figure-8.** The effect of distance in medium rain weather.

Figure-9. The effect of distance in light rain weather.

Optimization of receiver diameter aperture FSO

Receiver diameter aperture is one of the important parameters in designing the FSO system because it can influence the performance. The transmitter diameter aperture is set to 2.5 cm and the distance is fixed at 1 km. The transmission is carried out for the worst condition weather which is heavy rain with 19.28 dB/km of attenuation.

Figure-10 shows the BER performance in the heavy rain weather. As the receiver diameter aperture is increased, the BER is decreased. At 10 Gb/s, it required minimum diameter receiver aperture of 15 cm and 40 Gb/s required 21 cm to obtain the BER of 1×10^{-9}.
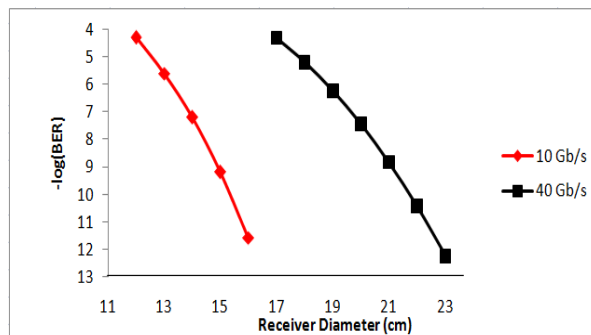

Figure-10. The receiver diameter aperture optimization in heavy rain.

CONCLUSIONS

The performance comparison of three different modulation techniques; non-chirped NRZ, chirped NRZ, alternate-chirped NRZ modulation formats was evaluated in Malaysia weather for the FSO system. The optimization of the diameter receiver aperture also been investigated at the worst weather condition which is heavy rain. The simulation work has been conducted using three modulation formats and modulated by 1550 nm CW laser. The transmission distance is set at 1 km for 10 Gb/s and 40 Gb/s for all type of weather conditions in Malaysia. The performance against the input power, distance and receiver diameter aperture are accessed at BER of 1×10^{-9}. The presented simulation of these three modulation techniques shows that alternate-chirped NRZ has slightly better performance among others for all five different wether conditions; clear weather, haze, light rain, medium rain and heavy rain. The bit error rate (BER) decreased as the optical input power is increased and vice versa for the propagation distance. For optimization receiver diameter aperture of FSO, the performance is getting better when the diameter is bigger. For a data rate of 10 Gb/s, the optimal receiver diameter aperture for the FSO system with 1 km transmission distance is 15 cm and for a data rate of 40 Gb/s, the optimal receiver diameter aperture is 22 cm.

In this paper we have successfully simulated the FSO system with three different modulation techniques. We proposed that these alternative modulation techniques can be applied in the future FSO system.

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