COMPARISON 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; NRZ pulse formats, 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 propogated 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 $1x10^{-9}$. 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.
Key words: Free Space Optic (FSO) · Non Return Zero (NRZ) · 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 candidate for future broadband communications, offering high transmission rates far beyond possible by radio frequency (RF) technology. Besides a high data transfer, a direct line-off sight FSO link offer numerous advantages compared to the conventional wired and radio frequency (RF) wireless communications (Zin, 2010). FSO links consume a relatively low power, offer a high security due to beam confinement within a very narrow area 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).

The pre-chirping of optical pulses at the transmitter side enables an improvement of transmission performance of the system. Therein, the pre-chirp can be realized using passive (e.g. fiber piece, optical filter) or active (e.g. MZM, phase modulator) components. The implementation of the pre-chirp causes a broadening of the signal spectrum, thus reducing the tolerance to residual dispersion and to 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 $1x10^{-9}$.

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 becomes appealing to research community due to its huge bandwidth, low bit error rate, license free operation and it easy deployment. These features of FSO communications are very attractive for applications in free web browsing, electronic commerce, data library access, enterprise networking, work-sharing capabilities, real time medical imaging transfer and high speed interplanetary links (Rajbhandari, 2011). In tropical regions, with the absent of fog, heavy rain is the main causes 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).

Atmospheric attenuation

One of important FSO link parameter is related to the fact that the loss of the media (air) between the transmitter and receiver can vary in time due to the impact of weather. Therefore, it is important for FSO system to take weather conditions into consideration, such as, rain and haze .

Rain intensity factor is capable of attenuating laser power and cause system under performance in a free space optical (FSO) communication system (Willebrand, 2002). In general, weather and installation characteristics are the key factors that could possibly reduce visibility and also impair the FSO performance.

The FSO system performance depends on the attenuation value at different visibility level. Because haze results in more particles stay longer in atmosphere compared to rain, it presents more serious degradation on FSO performance. This process requires the FSO hardware to be installed temporarily at site to acquire the system performance. If the attenuation performance of the system is satisfactory, the system is then permanently installed and commissioned.

The transmittance of the laser power in the atmosphere is described by Beer's law in equation (1):

$$T(R) = \frac{P(R)}{P(0)} = e^{-\beta R} \quad (1)$$

where :

R : link range (m)

$P(R)$: laser power at range R (dBm)

$P(0)$: laser power at the source (dBm)

β : scattering coefficient (km^{-1})

Previous Study

The proceeding paper with title 'On The Study of the FSO Link Performance under Controlled Turbulence and Fog Atmospheric Conditions ' was proposed by S. Rajbhandari., et.al.

In (Rajbhandari, 2011) reports the study 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 ina 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 use of BPSK signaling increase the efficiency of the FSO link under fog conditions nevertheless implies a higher receiver complexity and lower normalized gain compared with OOK-NRZ. The effect of turbulence at FSO link communications is more severe and the Q-factor falls very sharply with the Rytov variance for OOK and PAM. On the other hand, the BPSK show significantly higher resilience to turbulence and offers up to 16 times higher Q-factor than PAM. The results show that there would be a trade-off necessary to select different modulation techniques to adapt with the changes of weather effect on the FSO link (i.e. fog or turbulence).

The proceeding paper with title 'Optimization of free space optics parameters: An optimum solution for bad weather conditions' was proposed by Hilal A. Fadhil., et.al.

Nowadays, development in the communications sector is very encouraging. In this article, a numerical expression and simulation modeling of a WDM FSO system have been investigated successfully. External parameters represented the different weather conditions proven the FSO performance was influenced very much by the rain and haze condition. However for the clear weather condition, a 150 km with 2.5 Gbps data rate has been successfully achieved. The simulation results indicate the tradeoff between simulation parameters (data rate, link range and input power). For example, at 2.5 Gbps under clear weather, the BER value of 2.72×10^{-11} is achieved for 150 km, while at 155 Mbps the BER value of 2.19×10^{-8} is achieved for 175 km transmission distance. The effects of weather condition has been presented both theoretically and experimentally (using OptiSystem version 7.0) and illustrates some useful comparison. For example, result of a propagation study on an FSO link at 850 nm, 1310 nm and 1550 nm on 150 km long path are presented. Given these wavelength; for longer links, heavy haze, light rain, medium rain and heavy rain become critical issue. Finally, short link range and low data rate can optimize the FSO system transmission components.

The proceeding paper with title 'Preliminary analysis on the effect of rain attenuation on Free Space Optics (FSO) propagation measured in tropical weather condition' was proposed by Suriza A.Z., et.al.

In (Suriza, 2011) reported that preliminary analysis on the effect of rain on tropical environment demonstrate that heavy rain can cause the interruption of the FSO link. From the preliminary result also it can be conclude that it is a need to have attenuation model that best represent tropical weather condition. So that more conclusive outcome on the availability of FSO link data in tropical region can be more dependable since the attenuation model that in standard use now is based on temperate region.

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 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 Fig. 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 NRZ signals. The signal is propogated in the FSO link model under different weather condition. The modulated signal of FSO system for transmission is all about the same for all modulations, but chirped NRZ has sine generator and phase modulator (PM) modulator and alternate-chirped NRZ has 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 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 range is due to multipath fading, FSO channel can vary considerably according to channel conditions and different weather conditions in Malaysia such as clear, haze, light rain, medium rain,and heavy rain conditions. 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 cooefficient is 1e-022 W/HZ. The performance of the system was charactherized by accessing the sensitivity of BER at $1x10^{-9}$ against input power and distance.

The effect of optical input power for the FSO system

The simulated result in clear weather is shown in Fig. 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 Fig. 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 Fig. 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 $1x10^{-9}$. Fig. 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 is the worst condition for this analysis. As shown in Fig. 6, the signals can not 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.

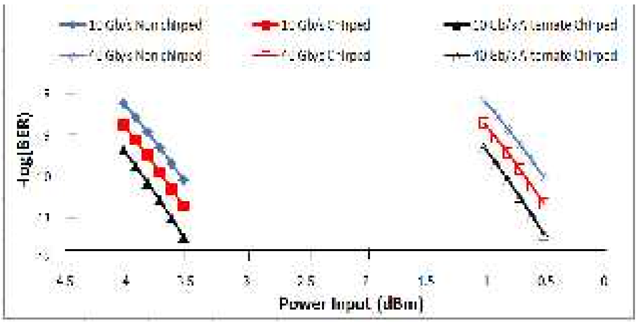

Figure 2 : The effect of optical input power during clear weather.

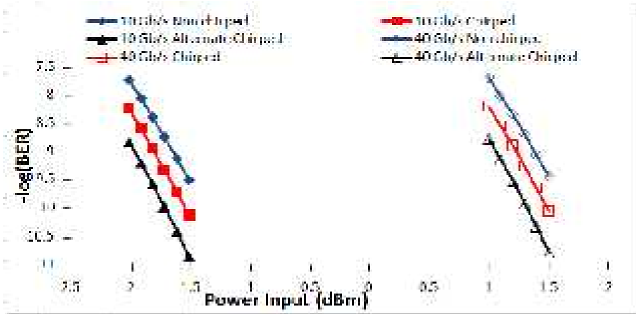

Figure 3 : The effect of optical input power during haze.

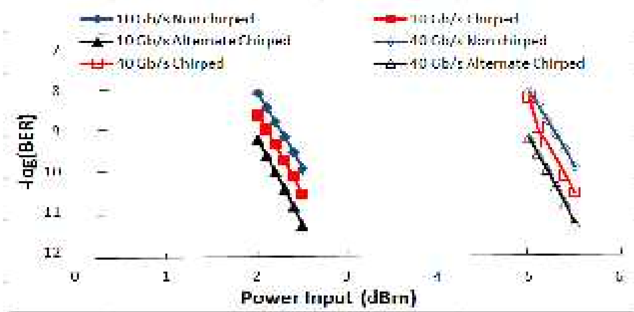

Figure 4 : The effect of optical input power during light rain.

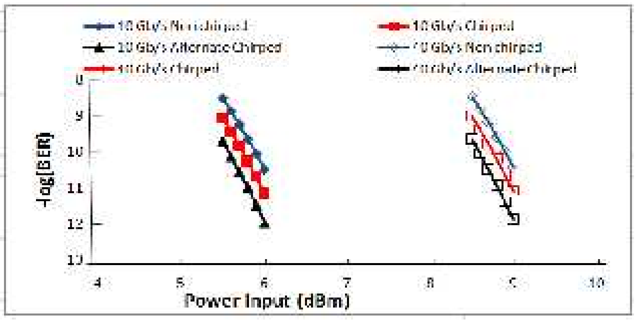

Figure 5: The effect of optical input power during medium rain.

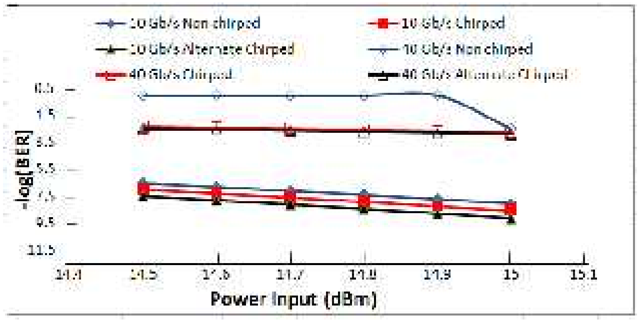

Figure 6 : The effect of optical input power during heavy rain.

The effect of distance in the FSO system

Fig. 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. Fig. 8 shows the maximum distance that the signal can be propogated 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. Fig. 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 $1x10^{-9}$.

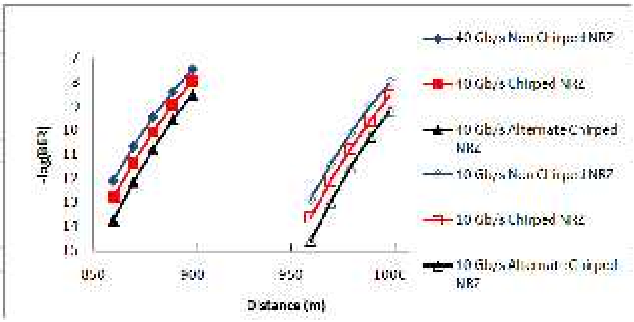

Figure 7 : The effect of distance in heavy rain weather.

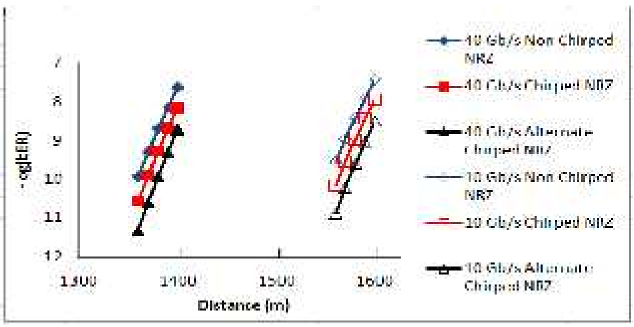

Figure 8 : The effect of distance in medium rain weather.

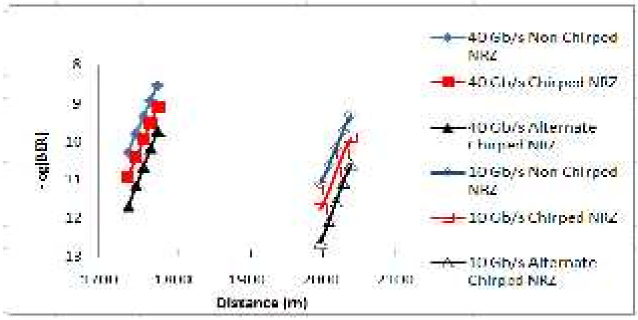

Figure 9 : The effect of distance in light rain weather.

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.

Fig. 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}.

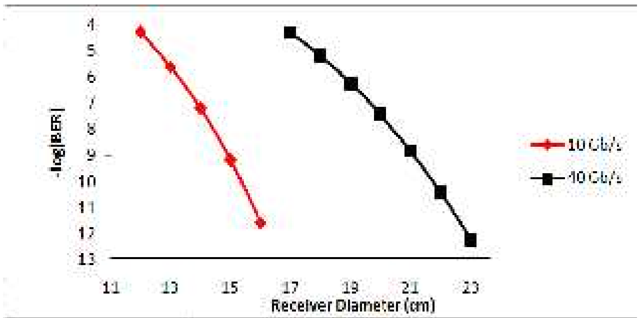

Figure 10 : The receiver diameter aperture optimization in heavy rain.

CONCLUSION.

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 aginst 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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