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Mitigation of losses for high speed data rate for wireless optical communication systems

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Abstract-This research paper demonstrates a time domain diversity reception method to improve the dependability of wireless optical communication connections distorted by atmospheric turmoil. Both Manchester and NRZ(non -return to zero) encoding have been analyzed in lab at a data rate of 1.25 gigabit per sec. Atmospheric turmoil has been modeled as having logarithmic normal variation for received signal intensity. Error in bit rate has been used as an indicator of system's performance. Results show that point where receiver power value falls below a threshold (outage probability) has reduced to <0.1% for Manchester coding from 3.2 percent (tolerance 0.1%) when time domain diversity reception is used.

Guiding terms-Atmospheric turmoil, diversity reception, link outage probability, bit error rate.

1. INTRODUCTION

Wireless optical communication is gaining large amount of attention so that it can be used for transmitting and receiving date in short range (<0.5 km) at high data rate. One such example is to provide optical wireless connection between buildings. But as it is well known that transmission of signals over air suffers from both attenuation and turmoil .Atmosphere attenuation puts up a barrier to maximum distance to which optical wireless signal can be transmitted using a source of some finite maximum power. On the other hand atmospheric turmoil results in fading of power of received signal. Although spatial domain diversity reception techniques have been developed to tackle the this signal perturbations, they require either two or more transmitter or receiver or even both, separated by a large distance in order to obtain a significant diversity gain[1-5]. Also this results into an increase in complexity of the system which makes it difficult to handle in real time. Therefore for the reasons mentioned above we put forward a technique called time domain diversity reception which increases connection dependability by reducing the bit error rate in a wireless optical connection. Unlike spatial domain diversity reception approach which utilizes more than one diverse paths to nullify the atmospheric distortions ,the time domain diversity reception reduces the effect of atmospheric turmoil by re-sending the signal to be sent after a particular amount of delay in time to diminish the declining of signal strength in channel (which continuously varies with time)[6]. Therefore mentioned scheme is easy to implement and can be easily achieved at low cost of implementation. This low cost is achievable by removing the data decoder and encoder (which make system more complex) of course by sacrificing system throughput overhead to obtain significant receiver sensitivity refinement in contrast to forward error correction. Also, if we use Manchester encoding, it provides us a reduced cost alternative to lessen the atmospheric distortions for gigabit connections since the prices of transmitter and receivers remains same even today at these operating bandwidths. In this research paper the time domain diversity reception method in laboratory environments by modeling the atmospheric turmoil induced fluctuation in intensity of received signal as logarithmic normal function of intensity has been experimentally demonstrated. For both Manchester and NRZ encoded signals, transmission performance in the influence of atmospheric turmoil have been studied at 1.25 gigabits per second. From the results about to come it becomes quite apparent that the signals encoded using Manchester coding have better performance than their NRZ counterparts for transmission over free apace. The better performance of Manchester encoded signals is due to their tolerance to fading even though they require a doubled line rate. Using optical amplifier at reception side the, sensitivity of the receiver has been refined for the diverse signals in wavelength domain by using demonstration[7-12].

II. OPERATING PRINCIPLE

Effect on received intensity by Atmospheric turbulence can be described by log normal function. The PDF is given as

$$P_{\mathrm{pdf}}(I) = \frac{1}{\sqrt{2\pi}\sigma_l I} \exp\left[-\frac{1}{2\sigma_l^2}\left(\ln I + \frac{1}{2}\sigma_l^2\right)^2\right] \tag{1}$$

Where log intensity fluctuation in transmission dependent variance is

$$\sigma_l^2 = 1.23 k^{7/6} C_n^2 L^{11/6} \tag{2}$$

Whose wavenumber is represented by k which is equal to $2\pi / \lambda$ where C_n^2 is refractive index constant which describe AT(atmospheric turbulence) strength and L is transmission distance . The value of AT varies from 10^{-17} which symbolizes weak turbulence to the 10^{-13} which symbolizes strong turbulence. The variation in atmospheric turbulence is too slow and based on millisecond scale. As received optical power varies we see a consequent a change in Bit Error Ratio. Retransmission of signal of suitable phase shift on millisecond scale depending on statistical properties of Atmospheric Turbulence is used to decrease the Bit Error Ratio. When there is imbalance between BER due to varying atmospheric properties the resultant Bit Error Ratio is decreased. Calculated variance for 500-m connection at 1550 nm is $5.5869*10^{-5}$ for a weak turbulence condition ($C_n^2 = 10^{-17}$. This calculated variance is greater than Gaussian noise variances induced by receiver by few orders.

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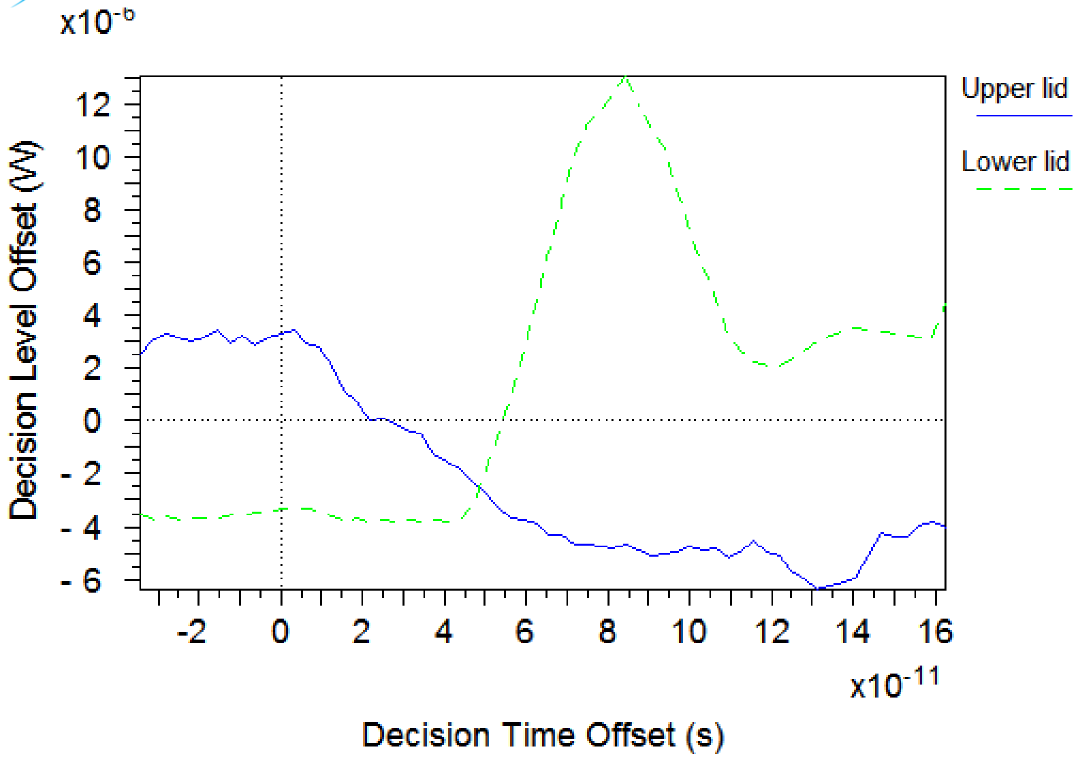

Fig 1: Graph of modeled atmospheric turmoil produced intensity variation at moderate turmoil with $\sigma_l^2=5.5869\times10^{-3}$

Photo receiver noise (Short noise: ~ 10^{-11}, thermal noise ~10^{-12}, at 300 Kelvin), noise of optical amplifier (spontaneous to spontaneous 10^{-11} and signal to spontaneous ~ 10^{-8}). This assessment indicates that weak atmospheric turbulence can give very high fluctuation in amplitude, increasing noise influence of free space link.For time realignment and detection, different copies of signals are separately detected at receiver and integrate with a buffer. Form bit patterns received most dominant bit pattern are taken, bits received in same slot are dominant bits, and this is used when any irregularity occurs.Predefined bit is obtained as result in case of even order diversity system .We see there occurs a same link condition between realigned copies Bit Error Rate remain same in case of dual-copy Diversity reception system .We also see when there is a difference between two error rates due to link condition, the final BER is decreased to nearly fifty *percent* of maximum of first and second error rate, hence we see a final decrease in the value of BER. Modeled intensity fluctuation is shown in fig 1.

III. Experiment and Results

Optical wireless system can be evaluated from Fig 2. Lasers which are operated at different frequency or wavelength comprises to form Time domain – diversity reception link. We can either implement techniques such as polarization diversity and subcarrier multiplexing or we can also use different wavelength for the easiness of testing in our process. it is observed that signal which are operated at different frequency or wavelength have almost same fading.

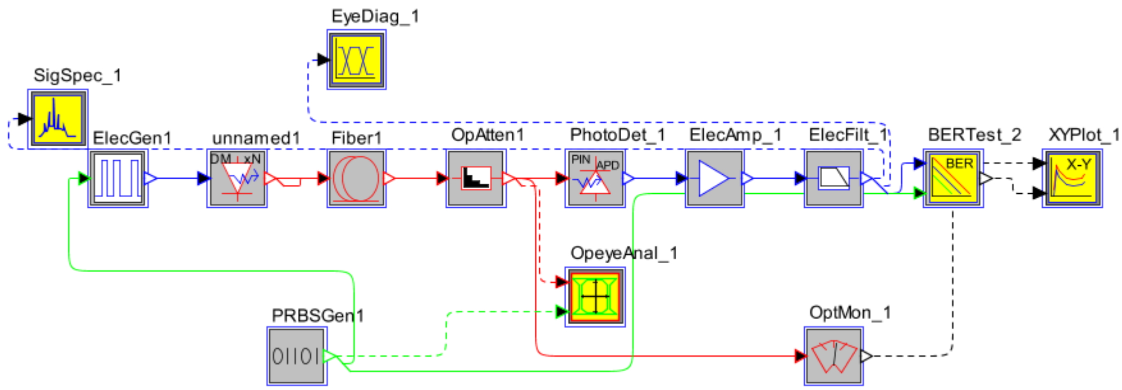

Fig 2: Structure for measurement of system capabilities of dual wavelength time domain diversity reception optical wireless transmission link

A characteristic at the C-band is considered. In experiment we combine more than one stream of signal with a coupler of 3-db and are used as input for optical attenuator which is computer controlled for the measuring of atmospheric turbulence fluctuation intensity. With the help of fiber collimator we passes emulated signal through the free space. For the safety of eyes we have fixed our output power at 0db. Receiver side was comprised of fiber collimator and a condenser of Galilean beam, we used both of them together to pass the light through a optical fiber(single mode). We preamplifier the received signal through fiber amplifier of erbium-doped type which comprises of ambient noise received through the receiver aperture. For the wavelength DE multiplexing of amplified signal we use a tunable bandpass filters and a 3-db coupler, the band pass filter wavelength is made comparable to the center wavelength with wavelength of laser under consideration. The suppression of amplified noise is done with the help of tunable bandpass filters with characteristics of 3-db wavelength, they also remove wavelength which has suppression ration greater than 40db. Conversion of optical fiber to electrical domain of low pass filter is perform through a photo receiver for the error correction. For Manchester and NRZ encoding the 3-dB bandwidth is 1.5 and 0.75 times of data rate, respectively. Signal bandwidth is doubled if we double the 3dB bandwidth of Manchester encoded signal. For fair assessment among two formats different LPF bandwidth is required. XOR operation used is used to carry out Manchester encoding on Non return to zero signal and clock of the system using an electrical XOR gate, its decoding is performed through a wide differential amplifier while preserving a 0.5 bit delay b/w consecutive two inputs.

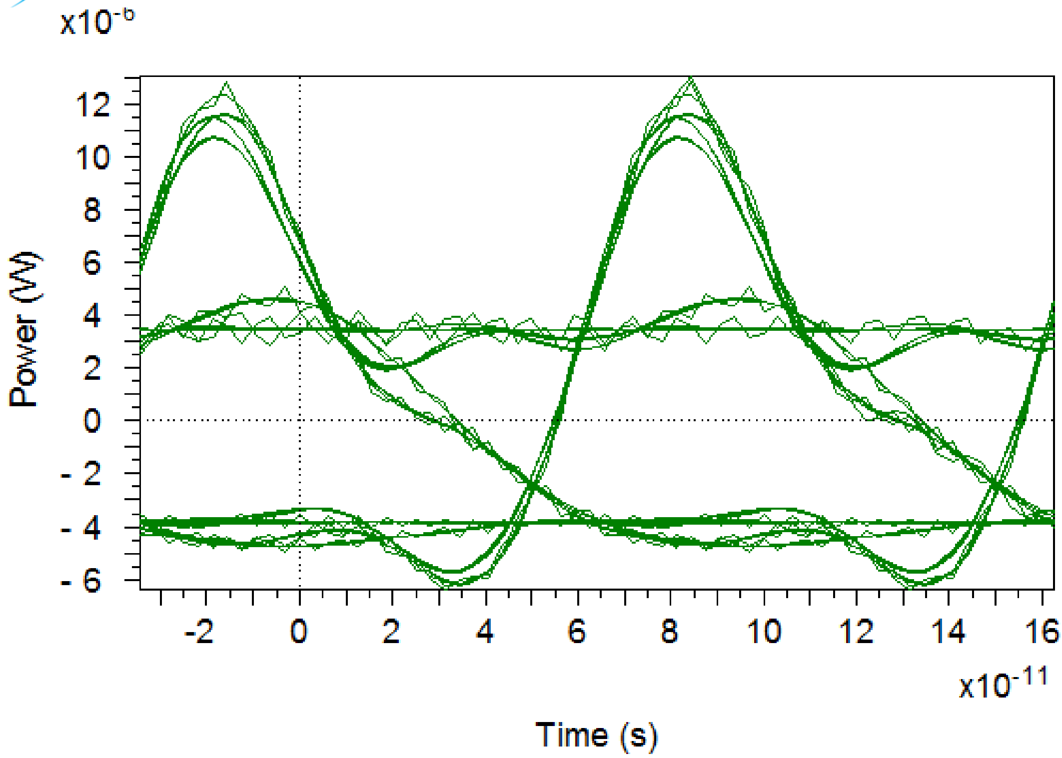

Fig 3: Graph of measured error in bit rate vs optical power received at 1.25 gigabit per second for (lower) Manchester encoded and (upper)NRZ encoded signals in various cases

It is also shown (in fig 3) the total Bit Error Ratio and its variation with total received optical power with respect to the subsampled result which is outlined in form of teared lines. Single frequency or wavelength which is equal to 1551.5nm is to be taken all the cases leaving the case of time domain diversity reception. The left most part of the curve in each graph shows Bit error ratio performance back-to-back when the turbulence is zero having a receiver sensitivity value of -0.47dB for Manchester by the help of wider low pass filter having low bandwidth. We observed a decrease in bit error ratio performance due to nonzero value of turbulence for non-return to zero signal. We see a slow variation in intensity fluctuation of Manchester signal resulting in half delay in differential decoding algorithm. We can show the performance of bit error ratio of time domain diversity reception on same graph. When we perform in time domain diversity reception systems two replicas of same signal are generated at dissimilar wavelength with same delay in time and which maintain total power to be emitted at 0 dB. When we set delay to millisecond we see an improvement in bit error ratio which also agrees with power spectral density of atmospheric turbulence. Under the following conditions we see a uncorrelated bit error rate of the copies that are transmitted so that bit-error can be obtained easily.

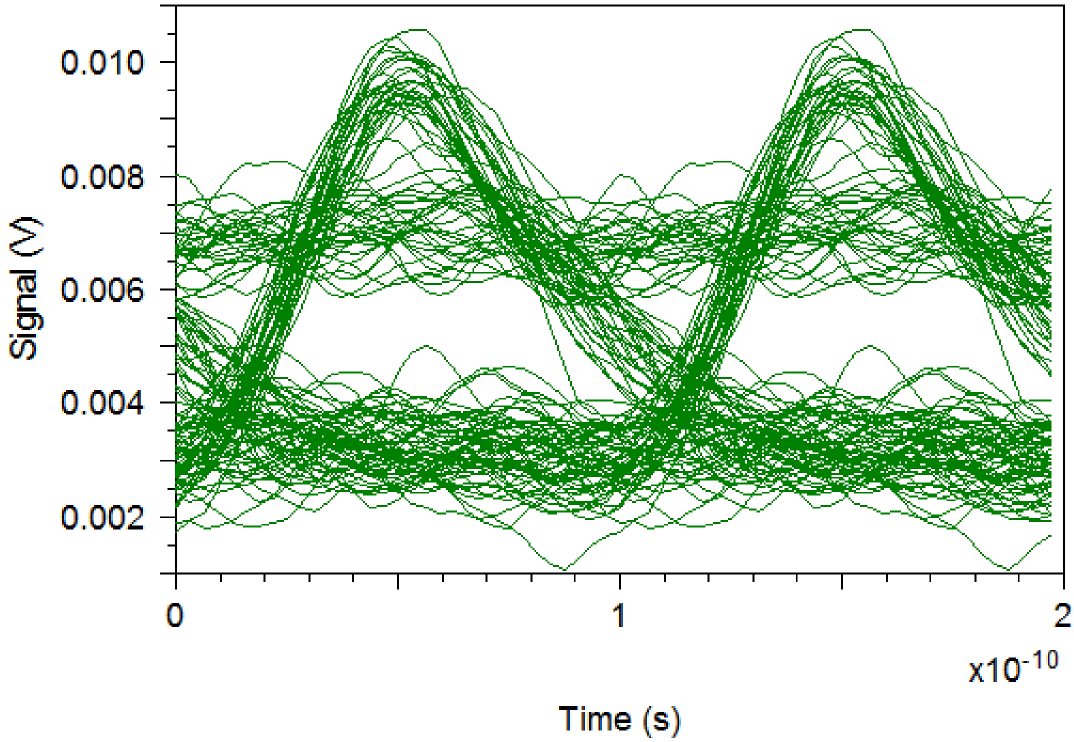

Fig 4: Eye diagrams of decoded Manchester (right) and NRZ coded signals for (a) turmoil free (b) σ_l^2=5.59×10^{-5} ,(c) σ_l^2=0.559 at an received optical power with mean of -28dBm.Time scale:200 picoseconds per division

At bit error rate 10^{-9} , the averaged time power drawback for signals encoded with Manchester coding and NRZ coding are 8dB and 10.9dB respectively σ_l^2=0.5587 and 4.1dB and 6.1dB for σ_l^2=5.5869×10^{-5}. Sensitivity of receiver is chosen to be -30dBm to deliver a power budget of 30dB while taking into account the losses occurring through propagation and coupling, suffered in a L=500 meters long free space link while practically deploying it ,as per local records of weather in Cambridge region of United Kingdom. Fig 4 displays the eye diagrams of signals received at receiver at specified turmoil levels. Receiver sensitivity refinement of 2.3 or 2.6 decibels is obtained for a channel affected by atmospheric turmoil (time varying) where signal are sent using Manchester encoding or Non return to zero encoding. To illustrate the consistency the time domain diversity reception in presence of atmospheric turmoil the link outage probability has also been studied. Link outage probability is the number of times (expressed in percentage) the resulting bit error rate is greater than 10^{-9}.When time domain diversity reception was used, the link outage probability was found to drop from 3.2 *percent*(tolerance 0.1%) to less than 0.1% for the signal encoded using Manchester coding and from 38.0 *percent*(tolerance 0.1%) to 9.8 *percent*(tolerance 0.1%) for signal encoded using NRZ coding ,at identical overall optical power received equal to -30dBm.The link outage probability for double wavelength multiplexed signal using Non return to zero encoding with reduced rate of data(0.5 times) is approximated to be 19.8 *percent*(tolerance 0.1%). This link outage probability implies that mitigating the rate of data to half can allow a temporal bit error rate refinement and superior sensitivity(time averaged) of receiver, but its reliance on the atmospheric turmoil is not mitigated in case of a time domain diversity reception system.

IV.CONCLUSION

Bit error rate reduction using time domain diversity reception and Manchester coding was revealed in this paper. Most exigent atmospheric conditions were pressed while keep in mind the absolute statistical characteristics of fading produced by atmospheric turbulence. From the results it becomes quite apparent that the proposed time domain diversity reception method promises a improved receiver sensitivity to signal transmitted in free space in laboratory conditions. One can also see transmitted signals which employ Manchester coding clearly show better results as compared to signals employing NRZ coding at all levels of turmoil. The link outage probability considering -30dBm received optical power at a bit error rate of 10^{-9} is refined by a magnitude greater than 96 *percent* by resending the 1.25-gigbit per second signal employing Manchester coding with an suitable time delay. The sensitivity of receiver is refined by 5dB and link outage probability drops significantly from 38 *percent* (with tolerance of 0.1%) to less than 0.1 *percent*, when both Manchester coding and time domain diversity reception is taken into use as compared to when a NRZ signal wavelength is sent. It is imperative to mention that this refinement in sensitivity of receiver (as depicted by mitigation in link outage probability) remunerates for half power reduction per copy in a diversity reception system and also gives a total net gain(due to diversity) to the sensitivity of receiver for superior transmission capabilities.The overhead of alignment for maintaining a line of sight transmission in spatial domain diversity reception is substantially mitigated by time domain diversity reception method as it enables atmospheric turmoil reduction with a solo pair of receiver and emitter aperture.

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