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BER Performance Analysis of an LDPC Coded OFDM Optical Wireless Communication System with Intensity Modulation and a Direct Detection Receiver

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Abstract: Optical wireless (OW) that is also known as free space optical (FSO) communication system are impaired by adverse weather conditions, such as rain, fog, cloud, snow and atmospheric turbulences. To reduce the destructive effect of atmospheric turbulence, OFDM technique itself have already been reported in several publications which is not sufficient to improve the performance. So channel coding with OFDM in OW havebeen proposed in literature. LDPC-coded OFDM enhances the immunity to the atmospheric turbulence in optical wireless communication systems. In this paper we provide a logical way to evaluate the exhibitions of LDPC coded OFDM OW correspondence framework with the impact of solid air disturbance. The scientific perception demonstrates that the framework endures penalty due to atmospheric turbulence and the degradations of BER are evaluated for several values of system parameters like number of OFDM subcarriers, code word length, interface separate, information rate and quality of the disturbance which is spoken to through refractive list structure parameter. Examination likewise demonstrates that the framework exhibitions enhances due to LDPC code and the coding addition of the LDPC coded OFDM framework with 64 sub-bearers are investigated. It is seen that LDPC coded OFDM OW framework gives 12 to 15 dB improvements over uncoded OFDM OW frame work at a BER of 10^{-9}.

Keywords: Carrier to Noise Ratio (CNR), Direct Detection Receiver, Free Low Density Parity Check (LDPC)Code, Orthogonal Frequency Division Multiplexing (OFDM), Optical Wireless (OW) Communication System

1. Introduction

Optical wireless (OW) communication systems are very much popular in recent days for its high speed data rate and bandwidth capacity [1]. However, the performances of OW communication system may seriously affected by the effect of atmospheric turbulence [2]. RF carrier modulation already been proposed in literature to improve the performances of OW communication under strong atmospheric turbulent condition [3-4]. Further, compared to multiple subcarrier modulated system single carrier modulated system suffers more severely due to inter symbol interference *(ISI)* caused by the dispersive fading of OW channels and thereby needs more complex equalization [5-6].

On the other hand, orthogonal frequency division multiplexing (OFDM) provides opportunities to use advanced techniques such as adaptive loading, transmit diversity and receiver diversity to improve transmission efficiency. A hybrid optical communication system that combines the RF OFDM and optical intensity modulation may improve the performances of OW communication system [7-8]. Again to improve the performance of OW systems, several coding techniques have been proposed earlier. However, in the presence of strong turbulence or deep fog, coding gains are insufficient and more advanced FEC schemes, such as low-density parity-check (LDPC) codes are needed [9]. Although the effect of atmospheric turbulence on coded OFDM systems are reported [10-12].

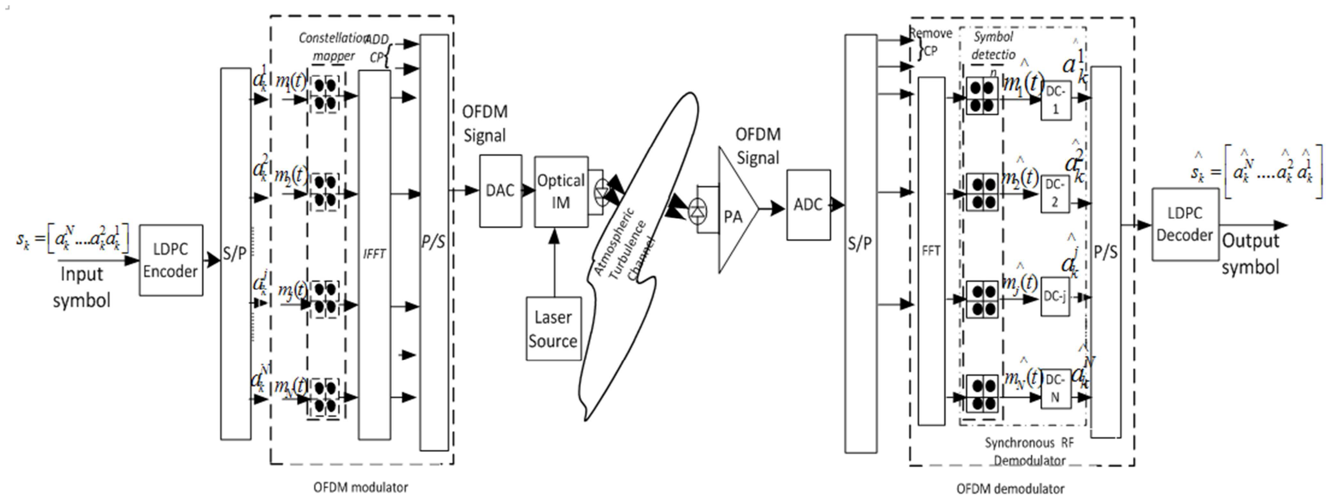

Figure 1. *LDPC coded RF OFDM Subcarrier Modulated Optical Wireless Communication System with Optical Direct Detection Receiver followed by RF Synchronous Demodulator.*

Most of the researches are performed in computer simulation form so it is difficult to realize the effectiveness of the parameters on the performances of OW communication link.

In this paper, we develop an analytical approach to investigate the performance of an OW communication link using LDPC code on RF OFDM modulation with optical intensity modulation in the presence of strong atmospheric turbulence. Analysis is developed to find the performance results analytically in terms of carrier to noise ratio and optimum number of OFDM subcarriers for a given BER for various link parameters.

2. System Model

The input data stream is paralleled and transmitted using N OFDM subcarriers. The data channels are modulated with PSK modulators and the modulators output are the input to Inverse Fast Fourier Transform (IFFT) block. Cyclic Prefix (CP) is added with the output of the IFFT block to mitigate the ISI effect and the overall output is sent to parallel to serial convertor. The output OFDM signal is encoded through LDPC encoder and the coded output is the given input to an electro optic intensity modulator (EOIM) and the EOIM output is then transmitted over an atmospheric turbulent channel.

At the receiving end the optical signal is detected by a direct detection receiver and the output photo detector current is amplified by a preamplifier. The output of the preamplifier is the LDPC coded OFDM signal with the effect of channel along with receiver noise. The output of the LDPC decoder is the received OFDM signal is passed through a serial to parallel converter. After removing the CP, the received samples are put to a Fast Fourier Transform (FFT) block and the output of the FFT is frequency domain signal of the OFDM subcarriers. Finally, the RF outputs are demodulated using synchronous demodulators followed by decision circuit (DC). The output of the DC is sent to parallel to serial converter to achieve the original data stream.

3. Theoretical Analysis

The electrical field output of *j-th* subcarrier modulator is given by:

$$s_k^j(t) = a_k^j\, p(t - kT_s)\, A_j \cos\omega_j t \qquad (1)$$

where ω_j is the *j-th* RF angular frequency. A_j is the amplitude of the *j-th* subcarrier.

$$s_k(t) = \sum_{j=1}^{N} a_k^j\, p(t - kT_s)\, A_j \cos\omega_j t \qquad (2)$$

Now the output of the subcarriers, s_k are provided to IFFT block and the output of IFFT can be written as:

$$S_{IFFT}(t) = IFFT\{s_k\} = \sum_{n=0}^{N-1}\sum_{j=1}^{N} a_k^j\, p(t - kT_s) e^{j\frac{2\pi nt}{NT_s}} \qquad (3)$$

The IFFT block Samples $S_{IFFT}(t)$ at t=lT_s which provides

$$A_{o,l} = S_{IFFT}(lT_s) = \sum_{n=0}^{N-1}\sum_{j=1}^{N} a_k^j\, p(t - kT_s) e^{j\frac{2\pi nl}{N}} \qquad (4)$$

To deal with inter carrier interference, a cyclic extension is added with the output of IFFT block. With the cyclic extension, the actual OFDM symbol duration is increased from T_s to $T = T_s + T_g$, where T_g denote the length of a cyclic extension. The samples are passes through a parallel to serial converter to produce OFDM signal.

The output of the intensity modulate optical carrier can be expressed as:

$$e_{opt}(t) = \sqrt{2P_T}\left[1 + k_a A_{o,l} H_T\right] e^{j\omega_c t} \qquad (5)$$

where P_T represents the transmitted laser power and k_a is the intensity modulation index and ω_c is the optical carrier angular frequency.

The received optical signal at the input to photodetector can be given as:

$$r(t)=\sqrt{2P_R I(t)}\left[1+k_a\sum_{n=0}^{N-1}\sum_{j=1}^{N}a_k^j p(t-kT_s)e^{j\frac{2\pi nl}{N}}H_T\right]e^{j\omega_c t}+n_b(t) \quad (6)$$

where $P_R=P_T\, e^{-\alpha L}$ is the received optical power, α is the attenuation coefficient of the atmospheric channel, L represents the link distance, n_b is the background radiation and I represents the turbulence induced fading.

The current i_d at the output of the PD is given by:

$$\begin{aligned} i_d(t) &= R_d\left|r(t)\right|^2 \\ &= 2R_dP_RI(t)+2R_dP_RI(t)\times k_a\sum_{n=0}^{N-1}\sum_{j=1}^{N}a_k^j p(t-kT_s)e^{j\frac{2\pi nl}{N}}h(t)+2R_dP_RI(t)\times H_T{}^2k_a{}^2\left(\sum_{n=0}^{N-1}\sum_{j=1}^{N}a_k^j p(t-kT_s)e^{j\frac{2\pi nl}{N}}\right)^2 \end{aligned} \quad (7)$$

where R_d is the responsivity of the photodetector.

The received OFDM signal is given by:

$$\begin{aligned} S_{OFDM} &= 2R_dP_RI(t)H_T\left(1+k_a\sum_{n=0}^{N-1}\sum_{j=1}^{N}a_k^j p(t-kT_s)e^{j\frac{2\pi nl}{N}}\right)+n(t) \\ &\cong 2R_dP_RI(t)H_Tk_a\sum_{n=0}^{N-1}\sum_{j=1}^{N}a_k^j p(t-kT_s)e^{j\frac{2\pi nl}{N}} \end{aligned} \quad (8)$$

Now the received OFDM signal is put into the serial to parallel converter and removes cyclic extension from the output. Then the output is forwarded to FFT block and the output of the FFT can be expressed as:

$$\begin{aligned} S_{FFT} &= FFT\{S_{OFDM}\} \\ &= \frac{1}{N}\sum_{l=0}^{N-1}2R_dP_RI(t)H_Tk_a\sum_{n=0}^{N-1}\sum_{j=1}^{N}a_k^j p(t-kT_s) \end{aligned} \quad (9)$$

The output of the FFT is frequency domain signal on the receiving subcarrier. Now the RF outputs are demodulated through synchronous demodulator.

The signal at the output of the RF demodulator is given by:

$$y(t)=\frac{1}{N}\sum_{l=0}^{N-1}2R_dP_RI(t)k_a\sum_{n=0}^{N-1}\sum_{j=1}^{N}a_k^j p(t-kT_s)+n_0(t) \quad (10)$$

The variance of the output noise $n_o(t)$ is given by:

$$\begin{aligned} \sigma_n{}^2 &= \sigma_{sh}{}^2+\sigma_{th}{}^2 \\ &= 2eB[R_d\,\mathrm{P}_r\,I\times k_a.A_{sc}(t)]+\frac{4kT}{R_L}B \end{aligned} \quad (11)$$

Now the Carrier to Noise Power Ratio conditioned on a given turbulence induced fading I can be expressed as:

$$CNR(I)=\frac{\left\|\left[2R_dP_RI(t)k_a\sum_{j=1}^{N}a_k^j p(t-kT_s)\right]\right\|^2}{2eB[R_dP_RIk_a.A_{sc}]+\frac{4kT}{R_L}B} \quad (12)$$

Under LDPC coded condition, the conditional PDF of the channel LLR approaches Gaussian distribution with an increasing number of iterations and is given by [9]:

$$P_Z(I)=\frac{\sigma_n}{2I\sqrt{2\pi}}\exp\left(-\frac{\left(t-\frac{2I^2}{\sigma_n^2}\right)^2}{\frac{8I^2}{\sigma_n^2}}\right) \quad (13)$$

where

$$t=\left|\frac{-(2k_1+nk_2)-\sqrt{(2k_1+nk_2)^2-4k_1(k_1+nk_2+n^2k_3-n^2R)}}{2k_1}\right| \quad (14)$$

The unconditional PDF of the channel LLR is obtained by averaging over the PDF of I by applying the integral in equation as [9]:

$$p_Z(t)=\int_0^\infty P_Z(t\mid I,r=+1)\,p(I)\,dI \quad (15)$$

where p(I) represents the probability density function of the received irradiance is given by: [13]

$$p(I)=\frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)}I^{\frac{(\alpha+\beta)}{2}-1}K_{(\alpha-\beta)}(2\sqrt{\alpha\beta I}),I>0 \quad (16)$$

where α and β are PDF parameters describing the scintillation experienced by plane waves and in the case of zero-inner scale.

The PDF of the check node message is approximated to be Gaussian and is given by:

$$p_u(t)=\frac{1}{\sqrt{4\pi m_u}}\exp\left(-\frac{(t-m_u)^2}{4m_u}\right) \quad (17)$$

where m_u is the mean value. The PDF of the bit node message can be obtained by convoluting (15) with (17) [13].

$$p_D(t)=p_u(t)\otimes p_z(t) \quad (18)$$

The BER per subcarrier is given by [6]:

$$BER_N(I)=\frac{1}{2}erfc\left(\frac{\sqrt{CNR(I)}}{2\sqrt{2}}\right) \quad (19)$$

Average BER under LDPC code is given by:

$$BER_{Avg(LDPC\ Coded)} = \int BER.p_D(t)dt \quad (20)$$

For Large number of subcarrier, the total average bit error rate is given by:

$$BER_{OFDM} = \frac{1}{N}\sum_{n=1}^{N} BER_n \quad (21)$$

4. Results and Discussion

Following the analytical approach provided in previous section, we evaluate the performance results of an LDPC coded OFDM OW communication link using Matlab. The parameters that are included for computation are listed in table below.

Table 1. *System Parameters used for computation.*

Parameters	Symbol	Values
Data rate	R_b	10 Gbps
Bandwidth	B	20 GHz
Code word length	n	1024
Subcarrier number	N	4 ~ 64
Laser wavelength	λ	1550nm
PIN photo detector Responsivity	R_d	0.85
Link distance	L	1000 m - 3600 m
Subcarrier amplitude	A_{sc}	1
Received power	P_R	-70 to 30 dBm
Refractive index structure Parameter	$c_n^{\ 2}$	$10^{-14}m^{-2/3}$1& $10^{-15}m^{-2/3}$

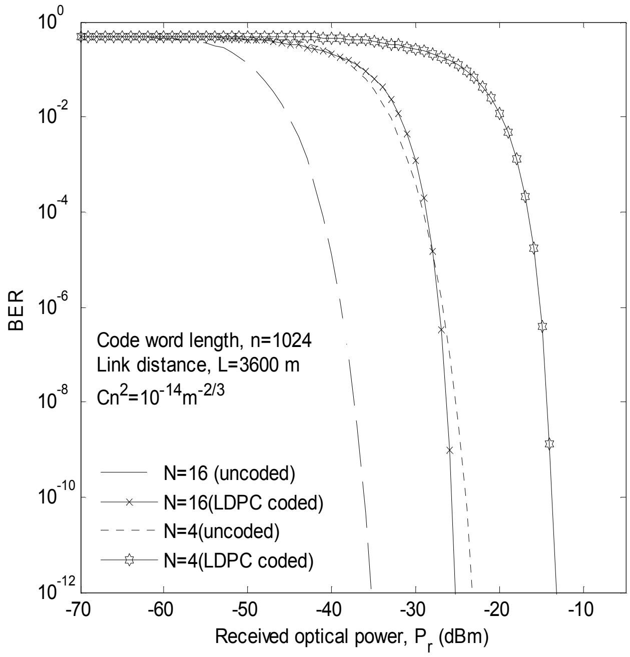

Figure 2. *Plots of BER versus received power for OFDM FSO communication system under uncoded and LDPC coded condition.*

The BER performances with respect to the received power for both uncoded and LDPC coded conditions are shown in figure 2. As expected the system performance improves gradually by increasing the number of subcarrier and it improves further due to LDPC code.For example, the BER performanec shown by 16 RF OFDM subcarriers under uncoded condition are achieved by applying only 4 RF OFDM subcarriers with LDPC code.

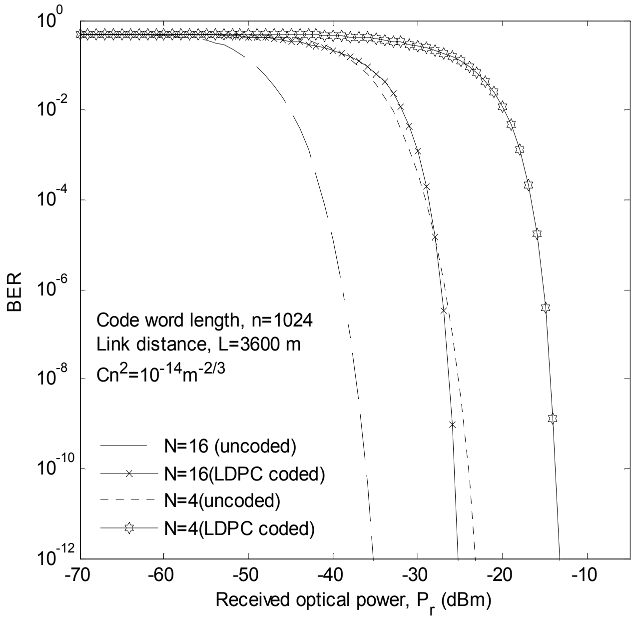

Figure 3. *Plots of BER versus received power for variable combinations of subcarriers under turbulent condition.*

And the improvements in BER performance due to LDPC code with variable combination of subcarriers are shown in figure 3. The analytical observation shows that the system suffers power penalty due to atmospheric turbulence and the system performance gradually improves by increasing the number of subcarriers.

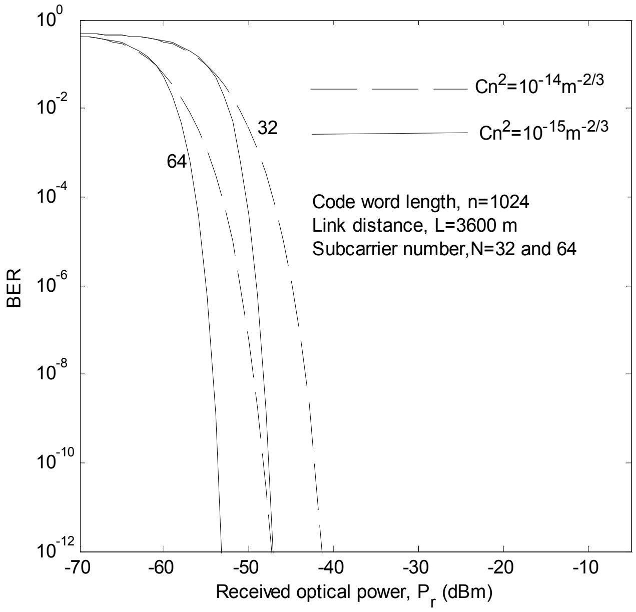

Figure 4. *Plots of BER versus received optical power with different refractive index structure parameter.*

Figure 4 shows the plots of BER versus received optical power with two different refractive index structure parameters. From the figure it is found that the system performance improves by changing the refractive index structure parameter, C_n^2 from 10^{-14} to 10^{-15}.

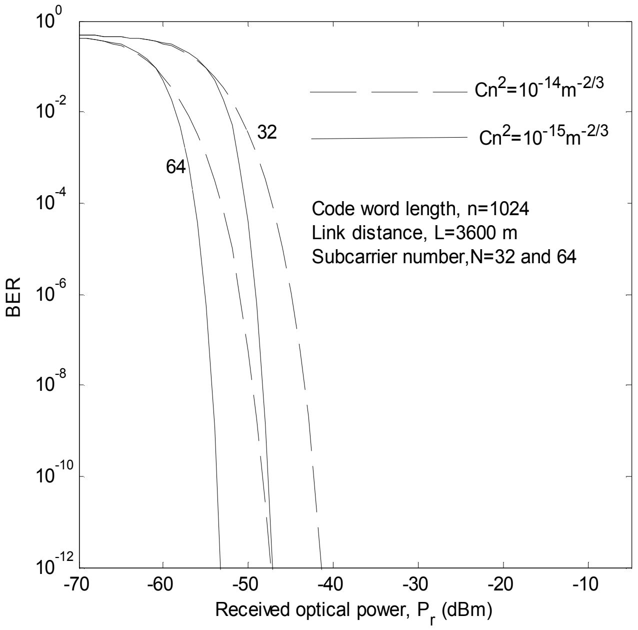

Figure 5. *Plots of BER versus Received optical power with different code word length.*

The BER performances with respects to the received optical power for two different code word lengths are shown in figure 5. Figure demonstrates that the changing effect is not impressive on BER performances.

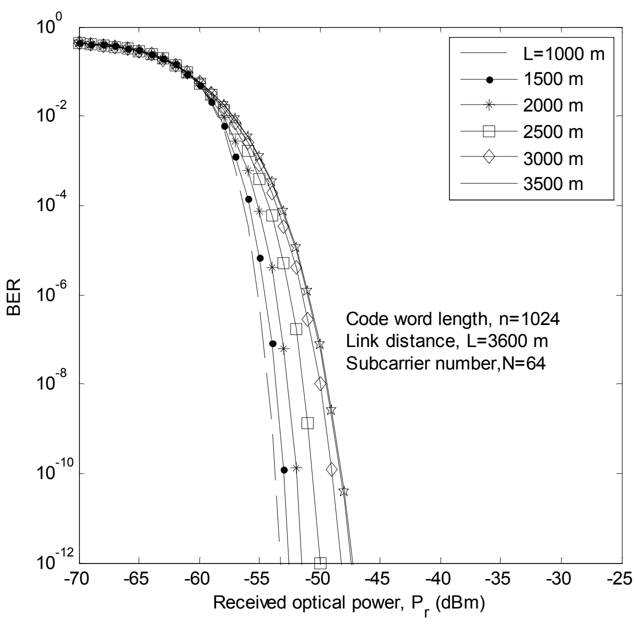

Figure 6. *Plots of BER versus received power with variation of link distance (m).*

Figure 6 illustrated that the error performance deteriorates as link distance is increasing from 1000m to 3600m. Moreover, it is evident that the system performance is less dependent on length when it increases from 3000 m to 3600 m compare to L increases from 1000m to 2500m.

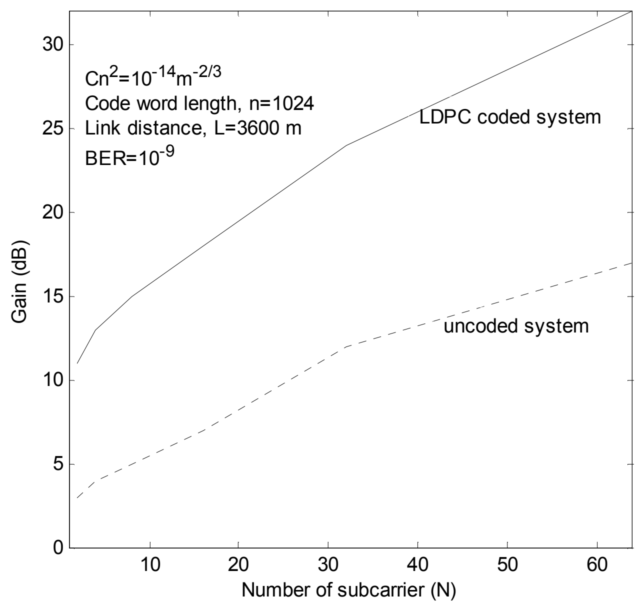

Figure 7. *Plots of Gain versus number of subcarrier for both uncoded and LDPC coded system.*

Next we compare the performance gain due to LDPC code in OFDM OW system. In figure 7 it is found that LDPC coded system offer a coding gain at a given BER compared to uncoded system. Results show that, coded OFDM in FSO provides 15 dB improvements over uncoded system at a BER of 10^{-9} for a link distance of 3600 m with 64 OFDM subcarriers.

5. Conclusions

An analytical approach is presented to evaluate the bit error rate performance of an LDPC coded OFDM optical wirelesscommunication system in presence of atmospheric turbulence which is modeled as gamma-gamma distribution. The analysis shows that system suffers severely due to atmospheric turbulence. But the hybrid technology that combines LDPC code with OFDM modulation may be a good candidate for OW communication under turbulent condition. Analysis also show that, OFDM itself provide better performance than FDM condition and LDPC coded OFDM system provides 12 to 15 dB improvements at BER of 10^{-12} over uncoded OFDM system. So the results of this research will find applications in design of high performance optical wireless link under turbulent condition.

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