International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Chromatic Dispersion Compensation in Long-Haul WDM Lightwave Systems

Manbir Brar, Dr. R.S.Kaler

C.G.C Jhanjeri, Mohali 140307, India, Thapar University, Patiala 147004, India

ABSTRACT:

Chromatic dispersion in Ultralong-Haul WDM LightwaveSystem can be compensated using combination of orthogonal frequency division multiplexing (OFDM) and optical single sideband modulation and phase/amplitude residual dispersions left are further adjusted by constellation rotation method. OFDM has better sensitivity than NRZ (Non Return to Zero) and does not require a reverse feedback path for compensation. In this paper Dispersion Compensation, received optical spectrum and BER v/s OSNR results are studied.

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Non Return to Zero (NRZ), Wavelength Division Multiplexing (WDM), Chromatic Dispersion (CD).

Introduction:

Orthogonal frequency division multiplexing (OFDM) due to its spectral efficiency has attractPed attention in recent years for the purpose to be applied in optical domain for high-speed optical fiber transmission. OFDM plays a significant role in the modem telecommunications for both wireless and wired communications. It has been demonstrated that optical OFDM is a promising technique of dramatically increasing the spectral efficiency in high-speed optical fiber channel, while improving the chromatic dispersion (CD) tolerance [1, 2].

Optical OFDM is classified into two categories- coherent detection and direct detection. Over last two decades, direct detection has been mainstay for optical communication but the recent progress in forward looking research has pointed to the trend that coherent detection is the future of optical communication.CO- OFDM (coherent detection optical OFDM) shows ultimate performance in receiver sensitivity, spectral efficiency and robustness against polarization dispersion. Fundamental principle of CO OFDM is to achieve high spectral efficiency by overlapping subcarrier spectrum yet avoiding the interference by using coherent detection and signal set orthogonality.

Electronic dispersion compensation (EDC) [3,4] is an alternative to optical dispersion compensation techniques such as DCF (dispersion compensating fiber), Bragg gratings, and optical resonators [5]. EDC is a method for mitigating the effects of chromatic dispersion. EDC reduces system capital cost as it eliminates optical dispersion compensators as well as it reduces total optical loss, amplification requirements. EDC also reduce system operating cost as it simplifies deployment and operation and also enables dynamic and remote network reconfiguration. EDC falls in three categories i.e. Compensation at receiver (Post compensation), Compensation at transmitter (Pre distortion), use of electronic processing to modify transmitted waveform.

Orthoganal frequency division multiplexing (OFDM) falls into third category as it uses electronic processing at transmitter and receiver. OFDM doesn't require any reverse feedback path and is resilient to multipath propagation and phase distortion. High dc bias is required

by OFDM to convert bipolar electrical to unipolar optical signals, which degrades the receiver sensitivity by more than 5 db. To overcome this, OFDM is given 1.8 db sensitivity advantage over NRZ.

It has been previously shown that if non linearity's are not considered then chromatic dispersion can be compensated by combination of optical OFDM with OSSB but when non linearity's are considered transmission over 4000 km was possible[5]. However, for the fiber optical channels with large number of subcarriers and wide bandwidth, the optical OFDM

signals are still sensitive to the phase rotation resulted from the Chromatic Dispersion. In this paper,chromatic dispersion in Ultralong-Haul WDM LightwaveSystem can be compensated using combination of OFDM and optical single sideband modulation and phase/amplitude residual dispersion will remain and is adjusted by using constellation rotation method (described in next section), which improves the quality of the transmitted OFDM signal.

The paper is organised as follows: section 2 includes logical model and description of constellation rotation method, section 3 includes system description, section 4 includes the results, section 5 concludes the paper.

Logical Model and description

The phase dispersion of the OFDM signal due to the Chromatic Dispersion can be expressed as

$$\Phi_d(f) = \pi.\, c.\, D_t.\, (f/f_{LD}) \qquad (1)$$

Here D_t is the total Chromatic Dispersion for the full fiber length in units of ps/pm, f and f_LDare the frequencies of the subcarriers and laser carrier respectively, c is the speed of light.

Due to Chromatic Dispersion phase rotation occurs around the origin so doughnut shape is observed in constellation diagram as shown in figure 1(a) for quadrature phase shift keying (QPSK) OFDM signals. Phase dispersion should be compensated to correctly demodulate the received signal and this can be done using several methods. One of the common way is to insert pilot tones into symbol stream periodically to get the phase dispersion in each sub carrier for compensation [6]. Though this method could effectively and flexibly compensate the phase dispersion, the insertion of pilot tone reduces data transmission efficiency, especially when pilot density is high.

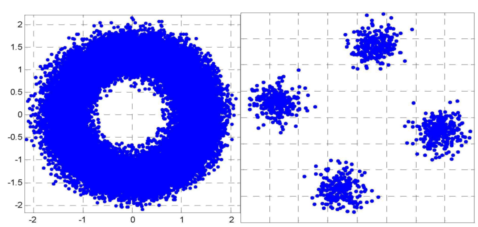
Suppose two pilot tones at different subcarriers indexed at PI and P2 are inserted in the first symbol of frame. Phase dispersion of m th subcarrier from eq (1) can be obtained as:

$$\phi_m = \frac{m^2 - p_2^2}{p_1^2 - p_2^2} \cdot \phi_{p1} + \frac{p_1^2 - m^2}{p_1^2 - p_2^2} \cdot \phi_{p2} \qquad (2)$$

Where ϕ_{p1} and ϕ_{p2} are the two phases of the two pilot tones indexed at P1 and P2, respectively. The calculated phase values of eq(2) can be used to compensate chromatic dispersion[6]. There are several other ways to compensate chromatic dispersion i.e combination of OFDM and optical single sideband modulation can be used to compensate chromatic dispersion in long haul WDM systems. Some residual dispersion remains that could be adjusted by constellation rotation method [6] described below:

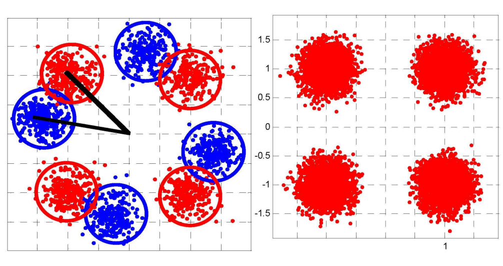
a. Rotate the phase dispersion $-\phi_m$mfor all the subcarriers.
b. Divide the constellation points into quadrants according to the subcarrier modulation format.
c. For each quadrant, calculate the center of the points, and the difference between the phase/amplitude and the theoretical constellation positions.
d. For each quadrant, make adjustment to all subcarriers, to compensate the phase/amplitude discrepancies.

Take QPSK OFDM signals as an example, Fig. l(b) shows one of the Chromatic Dispersion compensated subcarrier, where the phases are compensated by $-\phi_m$. The residual rotation is still visible in Fig. 1 (b), which is compensated as well by the constellation adjustment, as shown in Fig. l(c). Fig. l(d) shows the constellation of all compensated subcarriers.



1(a) all subcarriers before CD Compensation

1(b) One subcarrier, Chromatic Dispersion compensated.



1(c)One subcarrier CDcompensated

1(d)all subcarriers CD compensated

Fig. 1. Constellation of: (a) all subcarriers before chromatic dispersion compensation (b) one subcarrier, CD compensation, no constellation adjusted (c) one subcarrier, CD compensated, constellation adjusted (d) all subcarriers after chromatic dispersion compensation.

System Description

Fig 2 shows the spectral optical OFDM system.The system comprises the following subsystems:

Electrical OFDM Transmitter:

Data at 10 Gb/s are presented in 1024 bit blocks to 4-QAM. These modulators supply 512 inputs of inverse fast Fourier transform (IFFT). An interpolated waveform with well controlled spectrum is obtained by zero padding of IFFT inputs, this could be obtained with analog filters after digital to analog converters. We displace the OFDM sidebands from the optical carrier by modulating them onto a 7.5GHz RF subcarrier to give an RF sideband from 5 to 10 GHz so that practical optical filters can be used for carrier and sideband suppression.

Optical modulator and filter:

Mach-Zehnder modulators that are without linearization can be used in optical-OFDM systems [7]. Lower optical sideband is removed using an optical filter after modulation. The optical carrier is suppressed to increase the electrical received power for a given optical power, and so, the receiver sensitivity is improved.

FiberPlant :

The fiber link comprises 80-km spans of S-SMF with an optical amplifier before each span. The fiber has a dispersion of 17 ps/nm/km, a loss of 0.2 dB/km, a nonlinear coefficient of 2.6 $\times 10^{-20} m^2$ /W, and an effective area of 80 μm^2. The nonlinearity is modeled using the split-step method, as implemented in VPIsystems' V8.5. The amplifiers have a 16-dB gain and a 6-dB noise figure.

Receiver Model:

At the receiver, time-domain waveform proportional to the optical power is obtained using photodiode with a responsivity of 1 A/W and is noiseless to show the noise and distortion due to the optical amplifiers and fiber nonlinearity. The photocurrent is converted to inphase (I) and quadrature (Q) components by mixing with a $0^o$and 90^0phase of a 7.5 GHz local oscillator. The inverse procedures were carried out to get the OFDM signals: serial to parallel (S/P), remove CP, and Fast Fourier Transform. Once in frequency domain, each channel is equalized to compensate for phase and amplitude distortions due to the optical and electrical paths. This is easily achieved by using a separate complex multiplication for each QAM channel. After that, constellation adjustments were performed following the four steps as mentioned in section 2, to remove residual phase dispersion. The Q is extracted from the constellation. By assuming that the Cartesian axes are the decision thresholds, the Q is

defined as: $Q_{db} = 20.\log_{10}(q)$

where, $q^2 = \frac{\mu_x^2}{\sigma_x^2} = \frac{\mu_y^2}{\sigma_y^2}$with μ be mean value and σ^2 be variance as shown in fig 3. Bit error rate (BER) can be estimated using:

BER = $1/2erfc(\frac{q}{\sqrt{2}})$

For simulations with multiple WDM channels, $q^2$was averaged over all channels before conversion to Q(db).

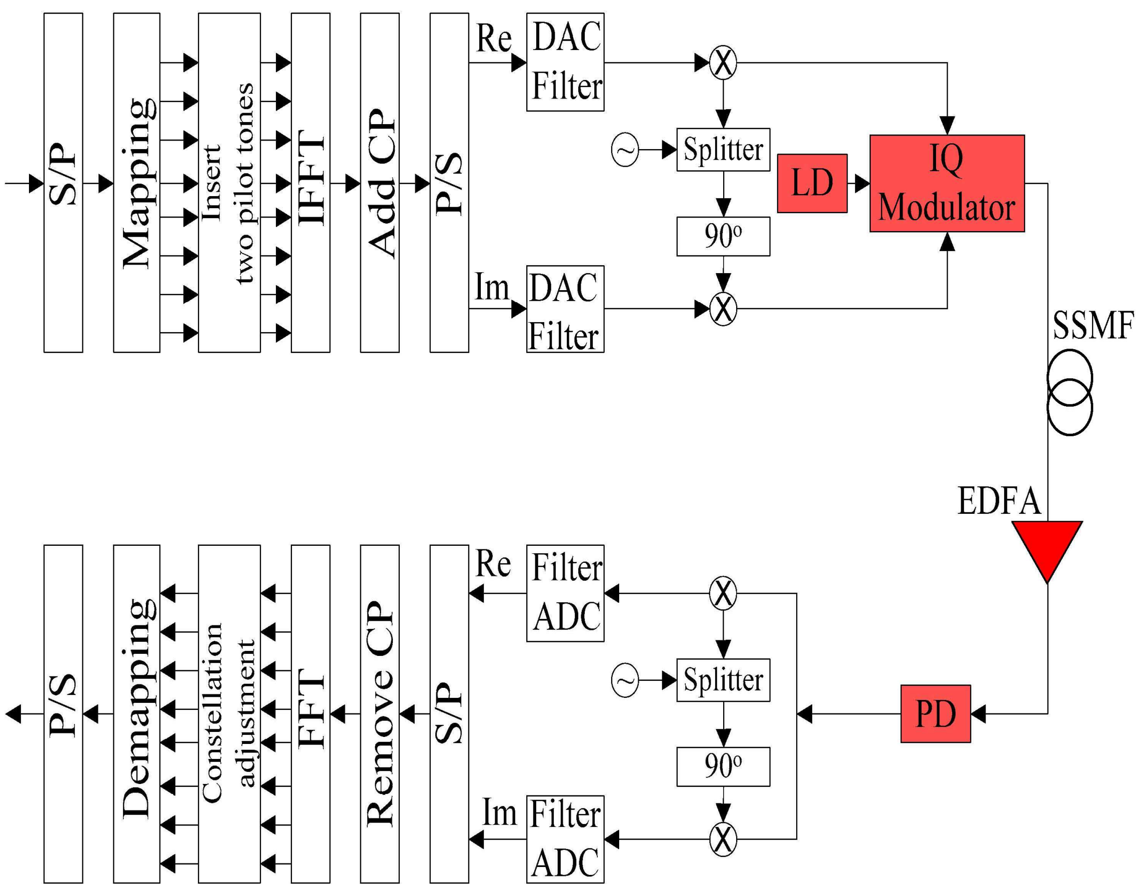


Fig.2. The schematical optical OFDM transmission system.

Results:

DISPERSION COMPENSATION

Fig 3 illustrates a typical received constellation before and after equalizer in the receiver. Before the equalizer, each constellation point form doughnut shape due to fiber chromatic dispersion. Phase dispersion is compensated after the equalization. But some residual phase dispersions will remain, which could be further adjusted by constellation rotation method described in section 2, so all chromatic dispersion is compensated for all the subcarriers which is shown in fig. 3. Hence Dispersion Compensation is perfect.

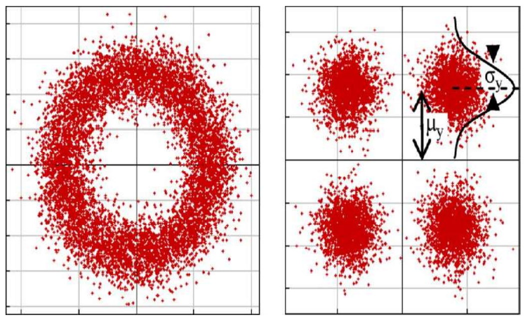


Fig.3. Optical constellations (left) before and (right) after equalization for an eight- channel 4000-km system with a −8-dBm fiber input power per channel.

RECEIVED OPTICAL SPECTRUM

A typical optical spectrum for an eight-channel system just before the optical demultiplexer at the receiver is shown in fig 4. The signal has propagated over 4000 km with an input power per channel to fiber span of −7 dBm. Noise will mix with the signals due to fiber nonlinearity. The WDM carrier spacing is 15 GHz, which allows for 5-GHz guard bands between the channels to allow demultiplexing with practical optical filters. The optical carriers have very small amplitude variations due to four wave mixing (FWM) between the carriers producing mixing tones that fall on top of the carriers. There is a far stronger variation in the amplitudes of the subcarriers, which should ideally be equal in amplitude for 4-QAM modulation. This variation will cause the QAM symbols within the constellationsto have amplitude errors. Phase errors also occur due to FWM because the mixing tones have a phase dependence on the phases of the OFDM subcarriers from which they were created.

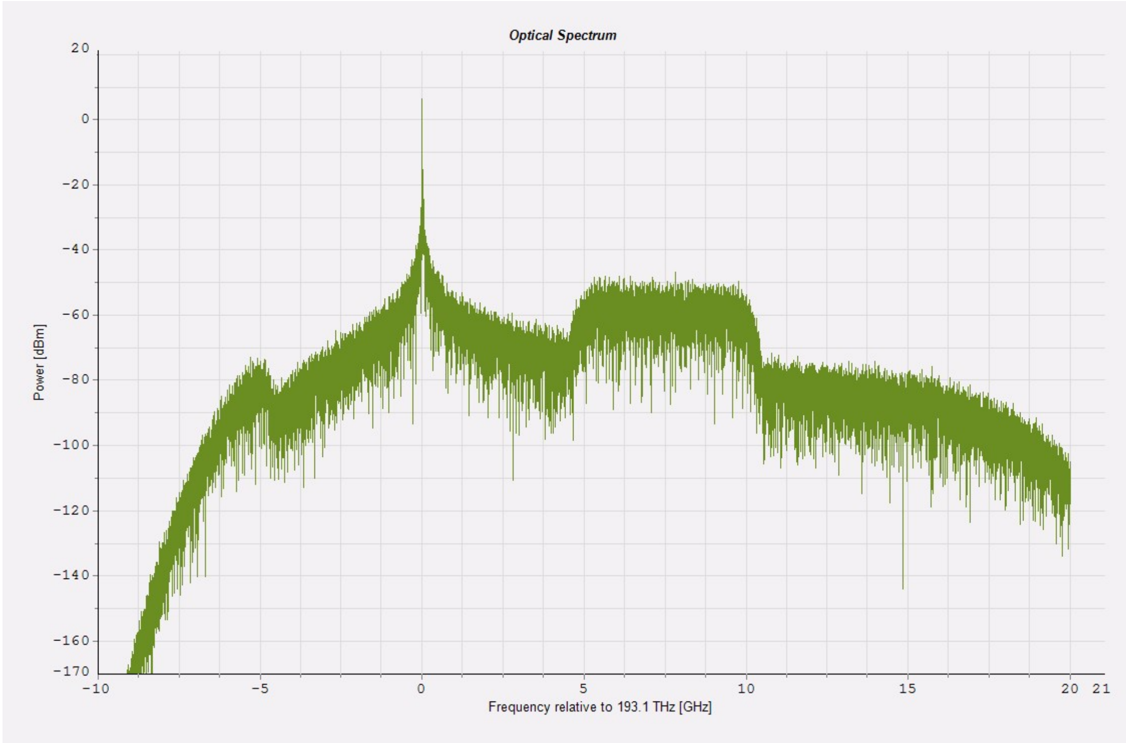


Fig.4. Spectrum after propagation through 4000 km of fiber.

BER v/s OSNR:

The BERs of NRZ and OFDM systems subject to the same OSNR were estimated. The OFDM system used a 10 GHz brickwall optical filter before the receiver. The NRZ system used a 20 GHz brickwall optical filter, with NRZ transmitter to be a zero linewidth laser and NRZ receiver to be a 7.5 GHz fourth order electrical Bessel filter [5]. Fig. 5 plots BER versus OSNR, measured over a 12.5-GHz bandwidth, which is equivalent to 0.1 nm at 1550 nm. NRZ requires a 0.5-dB better OSNR than OFDM for BER = 10^{-3} . The advantage of OFDM over NRZ reduces to zero for lower BERs.

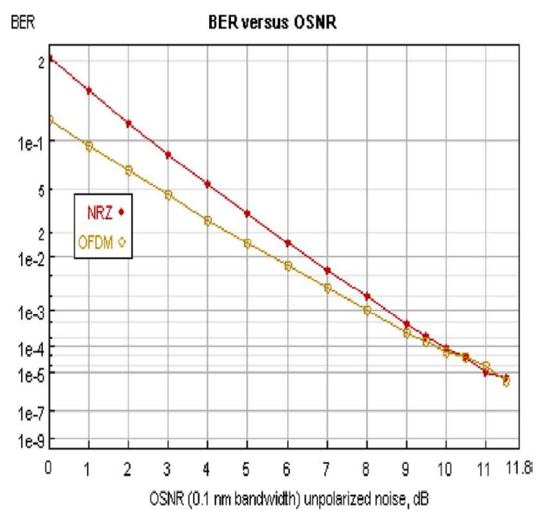


Fig 5. BER v/s OSNR for OFDM and NRZ systems.

CONCLUSION:

OFDM is a well-established technology that can compensate phase and amplitude characteristics of a communications channel, so that it offers a robust and adaptive method of increasing system performance. In this paper, we compensated phase and amplitude change of OFDM signals using combination of OFDM and OSSB and residual phase dispersions using onstellation adjustment method. The combination of OFDM and suppressed-carrier OSSB transmission can compensate ultralong-haul optical links, with better receiver sensitivity than a back-to-back NRZ system.

REFERENCES:

1. W. Shieh and I. Djordjevic (20lO). OFDM for optical communications, ELSEVIER Inc.
2. X. Liu et ai.(OFC 2009). A novel channel estimation method for PDM-OFDM enabling improved tolerance to WDM nonlinearity, OWW5.
3. D. McGhan (2006). Electronic dispersion compensation, presented at the Optical Fiber Commun. Conf., Anaheim, CA, Paper OWK1.
4. R. I. Killey, P. M. Watts, M. Glick, and P. Bayvel (2006). Electronic dispersion compensation by signal predistortion, presented at the Optical Fiber Commun. Conf., Anaheim, CA, Paper OWB3.
5. A. J. Lowery and J. Armstrong (2006). Orthogonal frequency division multiplexing for dispersion compensation of long-haul optical systems,Opt. Express, vol. 14, no. 6, pp. 2079–2084.
6. Lilong Liu et al. (2011). Chromatic dispersion compensation using two pilot tones in optical OFDM systems, vol. 8309.
7. M. Mayrock and H. Haunstein (2006). Impact of implementation impairments on the performance of an optical OFDM transmission system, presented at the Eur. Conf. Optical Commun., Cannes, France, Paper Th3.2.1.