Performance evaluation of 4 × 12 Gbps DWDM system using CO-OFDM detection scheme with and without dispersion compensation scheme

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***Abstract*—Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) is one of the technologies having ultrahigh capacity in transparent optical networks. CO-OFDM offers the most distant performance in spectral receiver sensitivity, spectral efficiency and polarization or chromatic dispersion tolerance. MIMO-OFDM opens path for doubling the spectral efficiency while providing robustness and polarization dispersion. Simulation of 4 × 12 Gb/s over Single Mode Fiber (SMF) for different distances is done and analysis is done on the basis of Bit Error Rate (BER) and Quality Factor (Q).**

***Index Terms*— CO-OFDM, WDM, dense wavelength-division multiplexing (DWDM), Dispersion Compensation**

I. INTRODUCTION

Orthogonal frequency-division multiplexing (OFDM) has been studied to overcome RF microwave multipath fading and has emerged as the leading modulation technology for the wireless and wire-line systems in RF domain. After, coherent optical OFDM (CO-OFDM) has been proposed [1] and has become a promising technique for high spectral efficiency and dispersion resilient transmission [2], [6], [8]. The need of coherent optical-orthogonal frequency division multiplexing (CO-OFDM) technology is to provide a very high capacity which is tolerant to chromatic and polarization dispersion and have high spectral efficiency and receiver sensitivity.

As the IP traffic continues to grow at high rate, the 100-Gb/s Ethernet is considered as the next-generation transport standard for IP networks [3]. As the data rate going to 100 Gb/s and beyond, the electrical bandwidth needed for CO-OFDM would be at least 15 GHz [4], [7] and is not cost-effective to implement even with the best commercial digital-to-analog converters (DACs) and analog-to-digital converters (ADCs) in silicon integrated circuit (IC) [5].

II. PRINCIPLE OF CO-OFDM

Coherent optical OFDM (CO-OFDM) requires the highest complexity in transceiver design. CO-OFDM was first proposed by Shieh and Athaudage, and the concept of the coherent optical multiple-input multiple-output OFDM was formalized by Shieh et al. A lot of work has been reported by many researchers.

The former CO-OFDM experiments were carried out by Shieh et al. for a 1000 km standard single-mode fiber (SSMF) transmission at 8 Gb/s and by Jansen et al. for 4160 km SSMF transmission at 20 Gb/s. Nevertheless, the fundamental principle of CO- OFDM remains the same: to achieve high spectral efficiency by overlapping subcarrier spectrum while avoiding interference by using coherent detection and signal set orthogonality. In this section, we describe the detailed principle of CO-OFDM, including analysis of transmitter and receiver design.

OFDM gives coherent systems computation efficiency and ease of channel and phase estimation. The coherent systems bring OFDM a much needed linearity in RF-to-optical (RTO) up-conversion and optical-to-RF (OTR) down-conversion. Consequently, a linear transformation is main requirement for the OFDM implementation. A generic optical OFDM system can be divided into five functional blocks: (1) RF OFDM transmitter, (2) RTO up-converter, (3) optical channel, (4) OTR down-converter, and (5) RF OFDM receiver

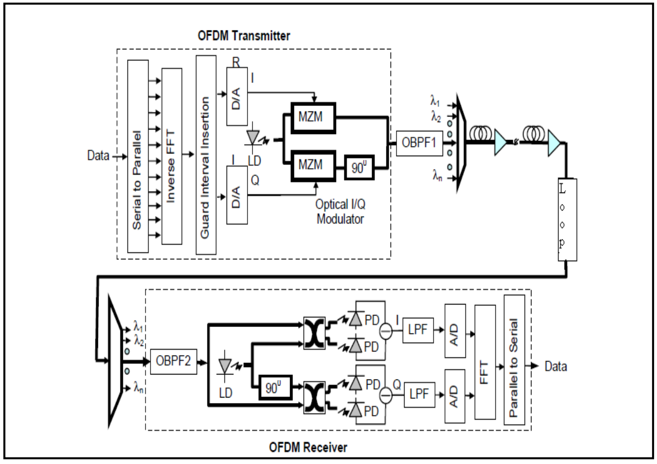

Fig. 1. CO-OFDM transceiver

It has been analyzed that by biasing the Mach–Zehnder modulators (MZMs) at null point, a linear conversion between the RF signal and the optical field signal can be achieved. MZM is biased at π because at this point non-linearity is minimum. The main purposes of coherent detection are (i) to linearly recover the I and Q components of the incoming signal, and (ii) to suppress or cancel the common mode noise. In coherent detection local oscillator laser is used at the receiver.

III. SIMULATION PARAMETER

The In this simulation we have used 4 channels each one of 12Gb/s using DWDM technology. The spacing between the channels is 50 GHz. The topology total transfer rate is 48 Gb/s. We have taken single mode fiber of 60 km, 120 km, 180 km, 240 km and 300 km, 360 km, 420 km, 480 km, 600 km, 900 km, 1200 km. The detection scheme is coherent detection. A 10 Gb/s data is generated using pseudo random binary generator, then this data is mapped by using QAM 4.

Then OFDM modulator is used for modulating mapped data. Using CW laser and MZM modulator OFDM data is modulated at 193.05 THz, 193.1 THz, 193.15 THz, and 193.2

THz for each channel. Then these modulated data are multiplexed using WDM multiplexer.

A local oscillator is used for coherent detection at the receiver. Then this signal is given to OFDM demodulator. Then output of OFDM demodulator is given to QAM-4 sequence decoder. The basic parameter of fiber are given in the table below

TABLE I. SIMULATION PARAMETER

Component	Parameter	Value
Fiber	Length Attenuation Dispersion Dispersion Slope	60 , 300 , 360 , 420 , 480 , 600, 900, 1200 km 0.2dB/Km 16.75 ps/nm/km 0.075 ps/nm^2/km
OFDM Modulator/ Demodulator	No. of subcarrier Position Array No. of FFT points No. of prefix points	512 256 1024 64
Tx CW Laser	Frequency Power	193.05,193.1,193.15, 193.2 THz -5 dBm
Rx CW Laser	Frequency Power	193.05 ,193.1, 193.15, 193.2 THz -2 dBm
Dispersion shifted fiber	Length Dispersion Dispersion Slope	10 km -83.33 ps/nm/km -0.375 ps/nm^2/km

IV. RESULTS AND DISCUSSION

Here we have taken 4 channels each one of 12 Gb/s. Output of 4 channels is multiplexed using WDM Multiplexer.

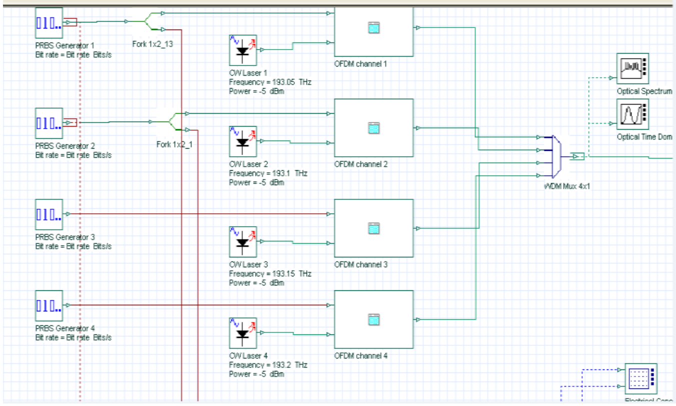

Fig. 2. Multiplexing of 4 channels

Optical link for 4 x 12 Gbps without dispersion compensation is shown.

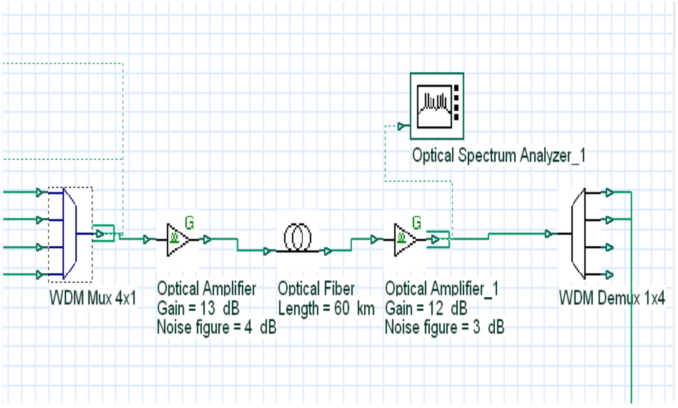

Fig. 3. Optical Link

De-multiplexing of 4 channels and their coherent detection is shown.

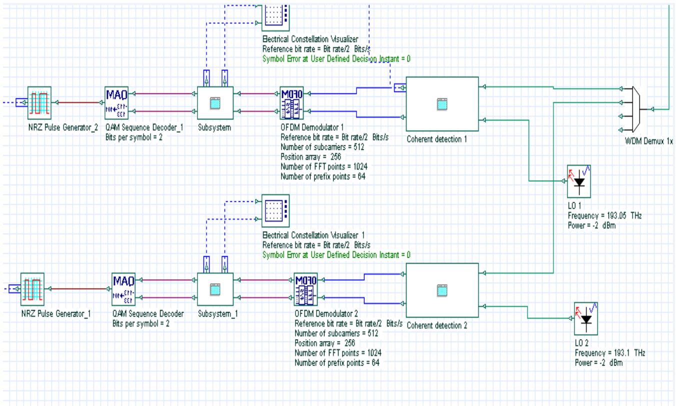

Fig. 4. De-multiplexing and coherent receiver

Optical spectrum analyzer output at mux output is shown

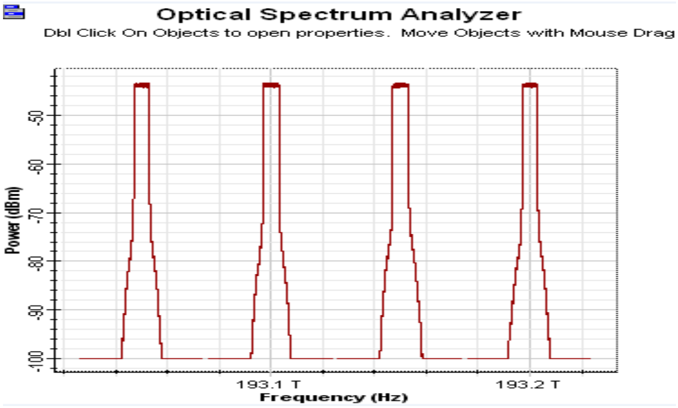

Fig. 5. Optical spectrum analyzer output at mux output

Now we will show electrical constellation diagram output in Fig. 6 after coherent detection for 60 km, 300 km, 420 km, 480 km, 600 km, 900 km, 1200 km.

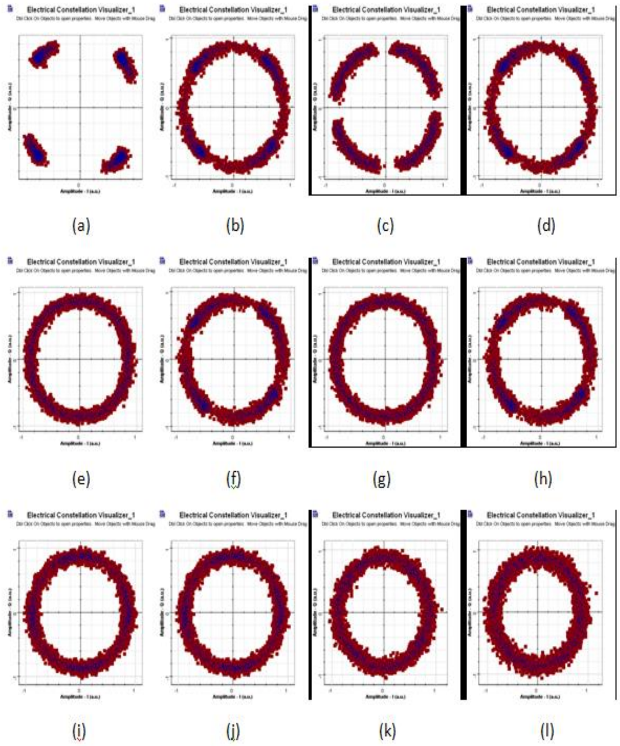

Fig. 6. Optical spectrum analyzer output at mux output Electrical constellation diagram output for (a) 60 km, (b) 300km, (c) 300 km with dispersion compensation, (d) 360 km,(e) 360 km with dispersion compensation, (f) 420 km, (g)420 km with dispersion compensation, (h) 480 km, (i) 480km with dispersion compensation,(j) 600 km with dispersion compensation, (k) 900 km with dispersion compensation, (l)1200 km with dispersion compensation.

Q factor or quality factor gives us the quality of signal with respect to distance of signal from the noise. It covers all the noises, dispersions and nonlinearities, which deteriorate the signal quality and thereby increase the bit error rate. It follows that the higher Q factor, the higher signal quality. Q factor is defined according to the following formula:

$$Q = (v_1 - v_0) /(\sigma_1 - \sigma_0) \qquad (1)$$

where $v1$ is a logic level "1", $v0$ is a logic level "0", $\sigma 1$ is a standard deviation of a logic level "1" and $\sigma 0$ is a standard deviation of a logic level "0".

In the figure 8 Quality Factor graph for one of channel of 4x12 Gb/s for 60 km distance is shown.

Bit error rate is one of the main indicators of the quality of optical connection. It is under the influence of the same parameters as the Q factor. Bit error rate gives us the ratio between the numbers of mistakenly received *bE* bits and the total number of the received p bits in dependence on time. The relationship is given by the formula:

$$BER = (bE) / (v * t) \qquad (2)$$

Where *v* is bit rate and *t* is time of measurement.

Now we will show the Q, BER for 4 X 12Gbps for different distances in the below table.

TABLE II

Q, BER FOR 4X 12GBPS CHANNELS FOR DIFFERENT DISTANCES

Distance	Q	BER
60 km	5.05×10^{49}	0
120 km	5.05×10^{49}	0
180 km	2.8527	0.0283164
180 km with compensation	5.05×10^{49}	0
240 km	1.81352	0.06277
240 km with compensation	5.05×10^{49}	0
300 km	1.47707	0.0867
300 km with compensation	5.05×10^{49}	0
360 km	1.30062	0.1046
360 km with compensation	12.2322	0.00167
420 km	1.20009	0.117032
420 km with compensation	2.98437	0.025945
480 km	1.02474	0.143256
480 km with compensation	1.71933	0.0677919
600 km with compensation	0.956404	0.154415
900 km with compensation	0.5275	0.2667
1200 km with compensation	0.3418	0.3382

V. CONCLUSION

Transmission performance for DWDM systems with coherent optical OFDM (CO-OFDM) is simulated including the fiber non-linearity effect. In this paper, we have first investigated the CO-OFDM performance of transfer rate 48-Gb/s based DWDM system with 50-GHz channel spacing. The simulation shows that capacity can be increased by using CO-OFDM in DWDM system and as the distance increases or capacity increases more dispersion comes into picture. The CO-OFDM system may simplify the long-haul link design and maintenance without a need for chromatic dispersion

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