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Use of Balanced Detection Scheme for Long Haul Optical Duobinary Links

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ABSTRACT
This paper investigates the use of balanced detection for a 32 channel duobinary modulated Dense Wavelength Division Multiplexing (DWDM) system with 40Gbps per channel, that is, a total capacity of 1.28Tbps for a repeaterless transmission distance upto 1,680km. We compare the performance of the system using both direct and balanced detection schemes at the receiver and it is found that balanced detection gives higher OSNR at the receiver which leads to an improvement in Q factor of around 0.5 dB. The paper also investigates the robustness of the duobinary modulation format to chromatic dispersion and Four Wave Mixing (FWM).
Keywords - Balanced Detection, Dense Wavelength Division Multiplexing, Duobinary modulation, Four Wave Mixing.

I. INTRODUCTION

Ever since the inception of Dense Wavelength Division Multiplexing (DWDM) technology, the focus is on optimization of the optical link in-order to enhance the data carrying capacity of the link. Mainly, the research was focused on either dispersion management or minimizing the non-linear effects like Cross Phase Modulation (XPM) and Four Wave Mixing (FWM) [1-3]. These non-linear effects mentioned before can induce cross talk between neighboring channels and create variations in channel power thereby leading to performance degradation [4]. Also, the use of higher bit rates is limited not only due to dispersion in optical fiber, but also due to requirement of higher Optical Signal to Noise Ratio (OSNR) at the detector. As a result, recent research is directed towards use of advanced optical modulation formats that can suppress effects of chromatic dispersion and Kerr Non-Linearities as well as provide high spectral efficiency of upto 4b/s/Hz with the help of DSP dispersion compensation algorithms [5]. Duobinary modulation is a modulation format that can be used to design a highly spectrally efficient DWDM link with better resistance to chromatic dispersion. Better spectral efficiency can be explained as the optical spectrum of duobinary modulated data is lesser than that of DPSK enabling us to reduce the inter-channel spacing. The detection of Duobinary modulation can be done using two simple techniques: direct detection and balanced detection [6].

In this letter, we elaborate on the use of balanced detection for optical duobinary modulation. Earlier research is on this technique focuses on its comparison with DPSK modulation and its compatibility with narrow spacing of 50GHz and significant Q factor improvement using balanced detection [6]. This letter advances the work and investigates its compatibility for long haul applications. Traditionally, for single ended detection only one photo-diode was used. For balanced detection, Mach Zehnder Delay Interferometer (MZDI) and two photo-diodes are used as shown in Fig. 2. MZDI generates a distorted AMI signal at its destructive interference output port and filtered duobinary component at constructive interference output port. Both of these help achieve good OSNR sensitivity [7].

For the optical link we have used an under-compensated (98%) link using about 10km of Dispersion Compensating Fiber (DCF) and 50km of Single Mode Fiber (SMF). Pre-compensation scheme is used and span analysis is done.

II. SIMULATION SETUP

For simulation of the long haul system, we have used Optisystem 7.0 simulation software. The software is used to solve Non-Linear Schrodinger's Equation (NLSE) using Time Domain Split Step (TDSS) method that can be used to evaluate both linear and non-linear effects of signal propagation

along the fiber. The proposed simulation setup consists of a 32 channel DWDM system transmitting data at 40Gbps per channel. The 40Gbps data stream is generated using Pseudo Random Bit Sequence (PRBS) generator of length 2^7-1 bits and 64 samples per bit. The wavelength spacing is maintained at 0.8 nm which translates into a frequency spacing of 100 GHz. The frequency range is 193.1THz to 196.2THz. The optical carrier wave generated by the DFB laser is modulated externally by Mach Zehnder Modulator (MZM) which generates duobinary modulated data. The incident power is 0 dBm per channel. The 32 channels are filtered at the transmitter using optical filters of bandwidth 60GHz and multiplexed for transmission onto a single fiber link.
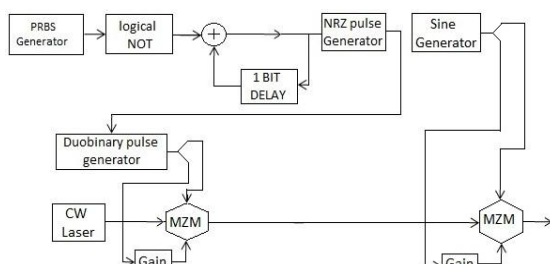

Fig. 1 Block diagram of duobinary transmitter

The fiber link consist of N spans of fibers with each span comprising of standard Single Mode Fiber (SMF) of length 50km and Dispersion Compensating Fiber (DCF) of length 10km to compensate for dispersion caused due to SMF. The attenuation coefficient of SMF is 0.2 dB/km, dispersion coefficient is 17 ps/(nm.km) and the dispersion slope is 0.081 ps^2/km. Non-linear coefficient for SMF is 2.6×10^{-20} m^2/W and effective core area is 80 μm^2.

TABLE I

Fibers	SMF	DCF
Length	50.1 km	10 km
Attenuation coefficient	0.2 dB/km	0.5 dB/km
Dispersion coefficient	17 ps/(nm.km)	-85.02ps/(nm.km)
Dispersion slope	0.081 ps^2/km	-0.4 ps^2/km
Non-linear coefficient	2.6×10^{-20} m^2/W	3×10^{-20} m^2/W
Effective core area	80 μm^2	30 μm^2

The attenuation coefficient of DCF is 0.5 dB/km, dispersion coefficient is -85.02 ps/(nm.km) and the dispersion slope is -0.4 ps^2/km. Non-linear coefficient for DCF is 3×10^{-20} m^2/W and effective core area is 30 μm^2. Pre-compensation scheme is used for dispersion management.

For each span, Erbium Doped Fiber Amplifier (EDFA) is used for compensating the attenuation in the fiber. Two EDFAs are used in each span, one after DCF with a gain of 5 dB and the other after SMF with a gain of 10dB. The noise figure of the EDFA is 5 dB.

The received signal is then de-multiplexed using Bessel filters of 60GHz optical bandwidth and order of 5. This signal is then given to the balanced detector and the detected output is then passed through an electrical filter of bandwidth 1xBit rate (40GHz). A BER analyzer calculates the resultant BER, Q factor and the eye opening.
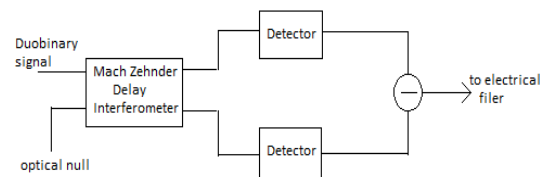

Fig. 2. Block diagram of Balanced Detector

III. RESULTS AND ANALYSIS

For reliable detection at the receiver, a Q factor threshold of 7.2 dB is selected which translates to a BER of 10^{-9} based on our simulation results.

At the receiver, on changing the detection scheme from direct to balanced, it was observed that the OSNR improved from 12.5 dB to 13.76 dB. Though balanced detection scheme suffered from Amplified Spontaneous Emission (ASE) noise [6], its performance was better than the traditional direct detection scheme.
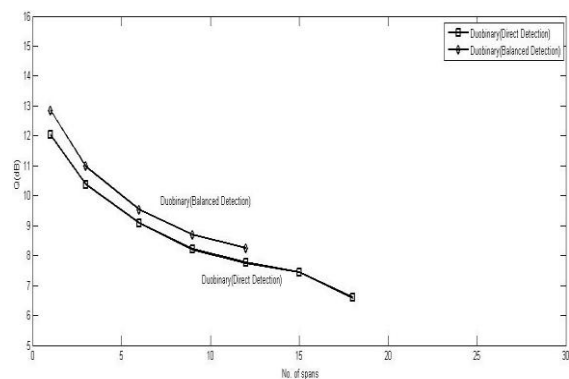

Fig. 3 Comparison of balanced detection and direct direction

For DWDM systems, if the input power exceeds a certain threshold, then the non-linear effects become dominant and it leads to increased BER. Hence in our simulation we have varied the input power from -5 dBm to 5 dBm as shown in Fig. 4. After analyzing the BER for different compensation schemes, it was seen that the maximum transmission distance of 1680 km was observed at Pin=0 dBm for an under

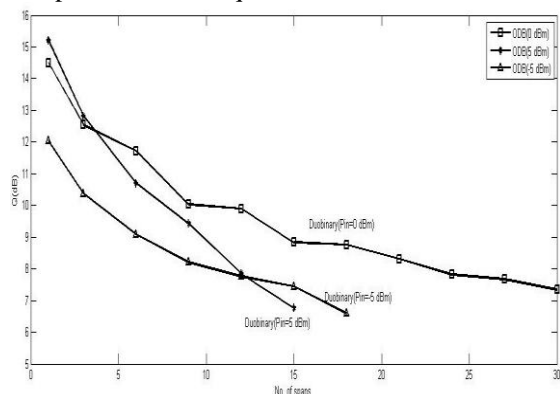compensated (98%) optical link using pre-compensation technique.

Fig. 4 Performance of Duobinary Modulation for Pin=-5dBm; Pin=0dBm and Pin=5dBm

The performance of duobinary modulation and NRZ modulation for varying lengths (number of spans) is illustrated in Fig. 5. The superiority of duobinary modulation can be explained on account of reduced pulse spreading due to a combination of phase as well as amplitude modulation. The results demonstrate an improvement of about 1.4 dB in the Q factor for the duobinary modulation as compared to NRZ modulation. On account of reduced sensitivity to chromatic dispersion and FWM, the duobinary modulated signal is capable of achieving larger transmission distances thereby highlighting its importance in long haul communication.
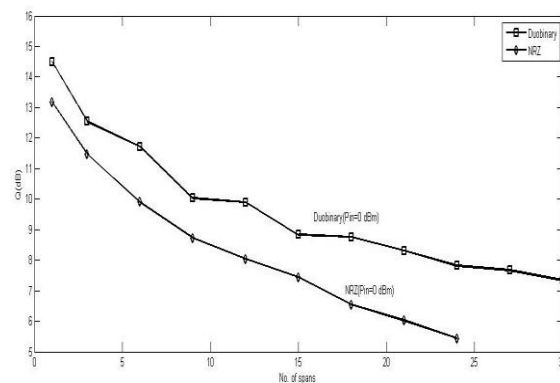

Fig. 5 Span analysis for Duobinary and NRZ modulation formats

The comparison between duobinary and NRZ modulation also demonstrates that the effect of Four Wave Mixing (FWM) is less pronounced in the former as can be illustrated from the Fig 6.
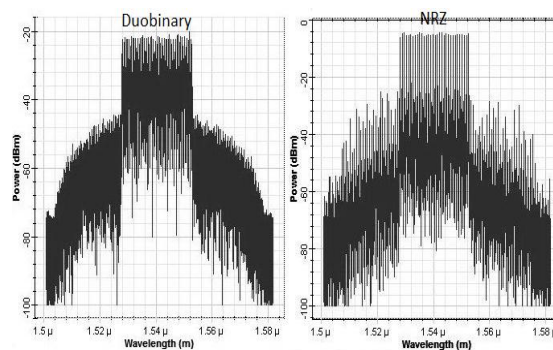

Fig. 6. Comparison of Four Wave Mixing (FWM) components for duobinary and NRZ modulation

IV. CONCLUSION

Based on the analysis performed in this paper, a dispersion under compensated link (98%) using pre compensation technique with an input power of 0 dBm and balanced detection at the receiver yielded a maximum transmission distance of 1,680km for duobinary modulation scheme.

Although balanced detection offered better OSNR and resulted in an improvement of 0.5 dB in the Q factor as compared to direct detection scheme, it was however limited by the ASE noise. If techniques are developed to reduce the ASE noise then balanced detection can offer even longer transmission distances.

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