IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 11, Issue 4, Ver. II (Jul.-Aug .2016), PP 36-42
www.iosrjournals.org

Analysis and Execution of 80 Gb/s PDM-DQPSK Optical Label Switching System with SAC Labels

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Abstract: *We present the performance of 80 Gb/s polarization division multiplexed-differential quadrature phase shift keying (PDM-DQPSK) optical label switching system with frequency swept coherent detected spectral amplitude code labels in simulation. 4 bits of 156 Mb/s spectral amplitude code (SAC) label are frequency-swept coherently detected. The label and payload signal performances are assessed by the eye diagram opening factor (EOF) and bit error rate (BER) as function of received optical power (ROP) and optical signal to noise ratio (OSNR). For back-to-back system and 138 km transmission, label eye opening factors are 0.94 and 0.86 respectively, while payload optical signal-to-noise ratio is 25.6 dB and the payload received optical power is -12.6 dBm for a bit error rate of* 10^{-9}*. The payload could well be demodulated after 1,260 km transmission at a BER of* 10^{-3} *using forward error correction (FEC).*

Keywords: *Coherent detection, optical label switching (OLS), polarization division multiplexed (PDM), polarization mode dispersion (PMD), spectral amplitude code (SAC).*

I. Introduction

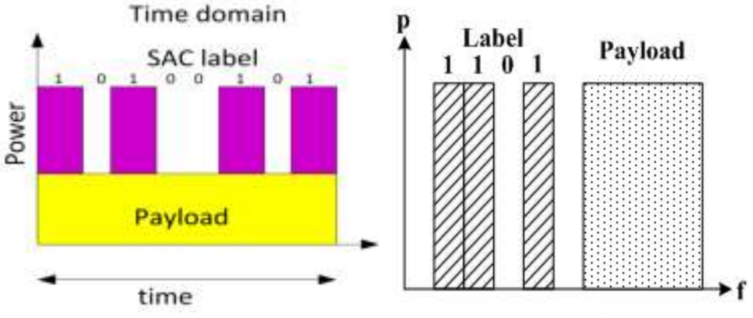
Optical communication has become one of the most important parts in modern communications due to the explosive growth of Internet data and services, and its developing direction is all-optical network (AON), with high-capacity and broad bandwidth. One optical technique used to improve the efficiency of optical communication systems is polarization division multiplexing (PDM). PDM serves to double the data rate using field-proven formats, Combined with differential quadrature phase shift keying (DQPSK), four bits are transmitted per symbol. The main challenge of this format is, however, to provide a precise and fast polarization tracking [1-3]. POLMUX implies a higher sensitivity to polarization effects, such as polarization mode dispersion (PMD) and polarization dependent loss (PDL). With respect to the single polarization case, penalties arise from PMD and PDL-induced crosstalk between the demultiplexed channels and from OSNR degradation by PDL [4–6]. Optical label switching (OLS) technique is considered a way to increase transmission speed in optical networks [7]. OLS beats the electronic bottleneck of system switches and disposes off optical-electronic-optical change to diminish the transmission delay. A straightforward and robust way of creating optical labels is the use of spectral tones [8, 9]. We introduce a SAC label detection system based on optical coherent detection, which produces an electronic signal that can be shaped into a control signal for an optical switching fabric by applying digital signal processing (DSP) algorithms. SAC has been applied in optical code division multiple access (OCDMA) and spectral code labeled systems [10, 11].

In this paper, we build a robust long haul transmission system to evaluate the transmission performance of 80 Gb/s PDM-DQPSK SAC label switching system in simulation using polarization tracker to recover the orthogonal polarization state of the PDM payload signal in order to mitigate the effects of polarization mode dispersion (PMD) and polarization dependent loss (PDL). We employed a novel method of frequency-swept coherent detection to decode SAC label, which reduces the complexity of label decoder. The high speed Payload is directly detected [12-15], which gets rid of complicated digital signal processing (DSP) procedure [16, 17].

The remaining parts of the paper are organized as follows. Section 2 provides a description of the operational principles of our proposed frequency-swept coherent detection for SAC labels. The simulation setup of SAC labelling scheme for 80 Gb/s PDM-DQPSK SAC label system with polarization tracker is presented in section 3. In section 4, the simulation result is presented and analyzed. We conclude the paper in section 5.

II. Principle of Frequency-Swept Coherent Detection

Coherent detection allows the greatest flexibility in modulation formats, as information can be encoded in amplitude and phase, or alternatively in both in-phase (I) and quadrature (Q) components of a carrier. The receiver exploits knowledge of the carrier's phase to detect the signal. In a SAC label framework, SAC label and payload occupy the same time space however different wavelengths. Labels are encoded in wavelength domain, and recognized by their amplitudes [18, 19]. Fig. 1 shows the schematic diagrams of SAC label in both time and wavelength domain.



(a) (b)

Fig. 1**:** Schematic diagrams of spectral amplitude code (SAC) label: (a) time domain and (b) wavelength domain.

The structure of a frequency swept coherent detection plan of SAC label is shown in Fig. 2. The SAC Label is shown in Fig. 2 (a) which has 4 bits code of "1010" in wavelength domain. In Fig. 2 (b), the frequency-swept local oscillator (LO) whose swept frequency covers the entire SAC label's frequencies is shown. The SAC label and LO are combined by a 3 dB coupler and the hybrid signal is transferred to baseband electrical signal in time domain after photo-detection (PD) as shown in Fig. 2 (c).

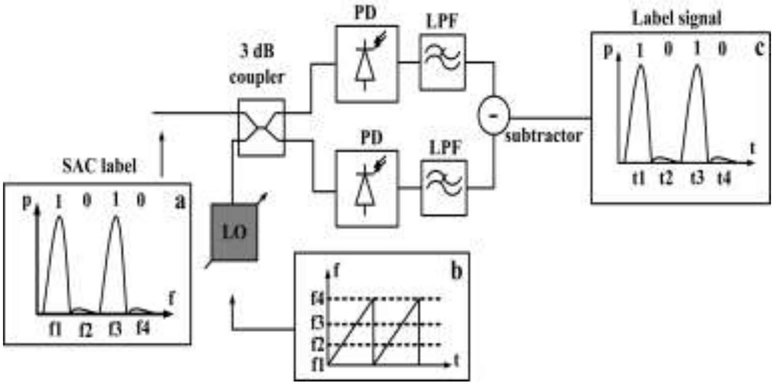


Fig. 2: Frequency-swept coherent detection of SAC label: (a) Wavelength domain, (b) Frequency-swept Local Oscillator, (c) Label signal in time domain.

III. System Model

The system setup of the 80 Gb/s PDM-DQPSK SAC transmission system is executed using VPI Transmission Maker 8.3 as shown in Fig. 3. A continuous wave (CW) laser at 1552.60 nm and 10 MHz linewidth is considered as optical source. Two orthogonal polarization channels are generated by one distributed feedback (DFB) laser source [20]. A 20 Gbaud DQPSK signal at 1552.60 nm is split by a polarization beam splitter (PBS) into two beams. One beam goes through 0 degree polarization controller (PC), while the other one goes through 90 degree PC after 1 ns delay to make two signals uncorrelated. A polarization beam combiner (PBC) is employed to combine the two orthogonal polarization signals into one beam of 80 Gb/s PDM-DQPSK payload. The SAC label generation unit is made up of a laser, an optical switch and a pseudo random binary sequence (PRBS) generator. For the generation of SAC label signal, a four-DFB laser array and a label encoder are applied, and at a label rate of 156 Mb/s. The chosen label laser wavelengths are at 1552.92, 1552.96, 1553.00, 1553.04 nm, respectively. The frequency interval between each label is 5 GHz while the spacing between payload and label is 40 GHz, so as to control the laser pulse signal and encode SAC label. By combining the payload and label, we obtain an optical packet of 80 Gb/s PDM-DQPSK payload and 156 Mb/s four-code SAC label.

A standard single mode fiber (SSMF) and dispersion compensation fiber (DCF) are used as the transmission fiber for each setup. For this part, chromatic dispersion (CD), polarization mode dispersion (PMD) and loss of SSMF are 0.16 ps/nm/km, 0.2 ps/km$^{1/2}$ and 0.2 dB/km, respectively, while the parameters of DCF are -0.8 ps/nm/km, 0.2 ps/km$^{1/2}$ and 0.5 dB/km, respectively. The polarization tracker is installed which recovers

0 degree and 90 degree of two orthogonal polarization states of PDM payload signal in order to mitigate the PMD impairment.

After polarization tracker, the packet is split to two branches by a 3 dB coupler and fed into both payload and label receivers to demodulate payload and label respectively. The payload is determined using direct detection. For the label, a frequency swept laser is simulated by using an optical frequency modulator with a range of 1552.91 to 1553.05 nm, in order to cover all the label available frequencies for each setup. The SAC labels are consolidated with the local oscillator (LO) by a 3 dB coupler. The electrical label signal is filtered by a 100 MHz dual-low-pass filter (LPF) and the original SAC label obtained.

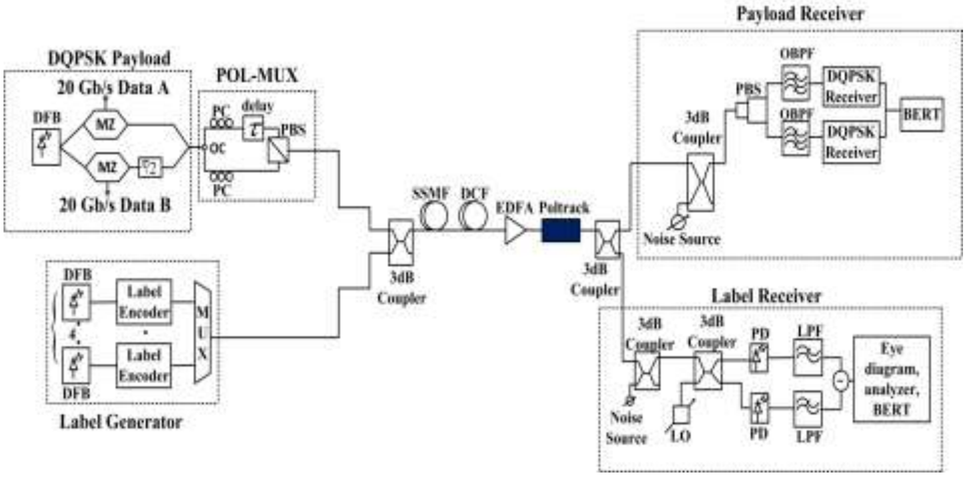


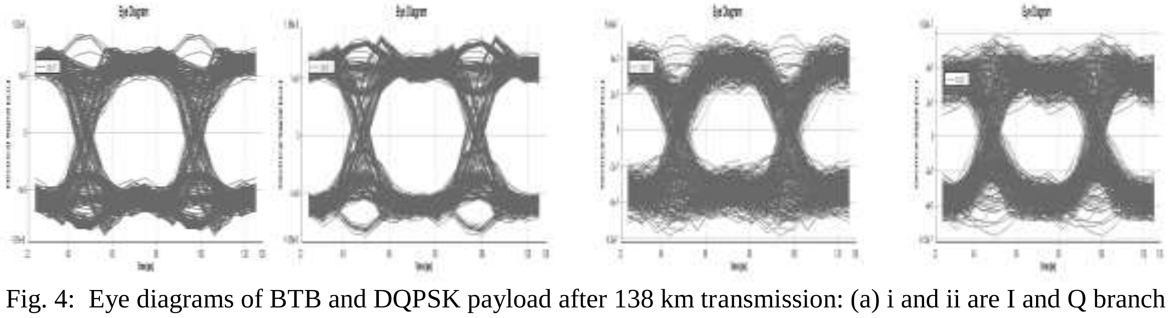
Fig. 3: Simulation setup of 80 Gb/s PDM-DQPSK SAC label system.

IV. Performance Analysis and Results of the System

Eye diagram is a very successful way of quickly and intuitively assessing the quality of a digital signal. It serves as an additional testing procedure for verifying transmitter output compliance, and revealing the amplitude and time distortion elements that degrade the BER for diagnostic purposes. Eye opening factor (EOF) is usually used to measure the received quality of SAC label. Its expression is:

$$\text{EOF}=\text{EA-}(\sigma_1+\sigma_0)\Big/\text{EA} \qquad (1)$$

where EA is the eye amplitude, σ_0 and σ_1 are the standard deviations of the sample points of ‘0’ bits and ‘1’ bits within the sample range. In our transmission, the EOF of the BTB is better opened than transmission after 138 km. For BTB, the label EOF is 0.94 whereas the label EOF after 138 km is 0.86. A long distance transmission of the SAC label with a high speed payload is achieved with the method of frequency-swept coherent detection. The eye diagram of I and Q components of the received DQPSK signal for back-to-back (BTB) and after 138 km transmission for 80 Gb/s is shown in Fig. 4. The polarization condition of the SAC labels is unusual after transmission yet in frequency-swept coherent detection, which is not sensitive to the label's polarization state; the SAC label can in any case be demodulated in our proposed system.


(a) Eye diagram of (BTB)

(b) Eye diagram of payload

(i) I Branch (BTB)

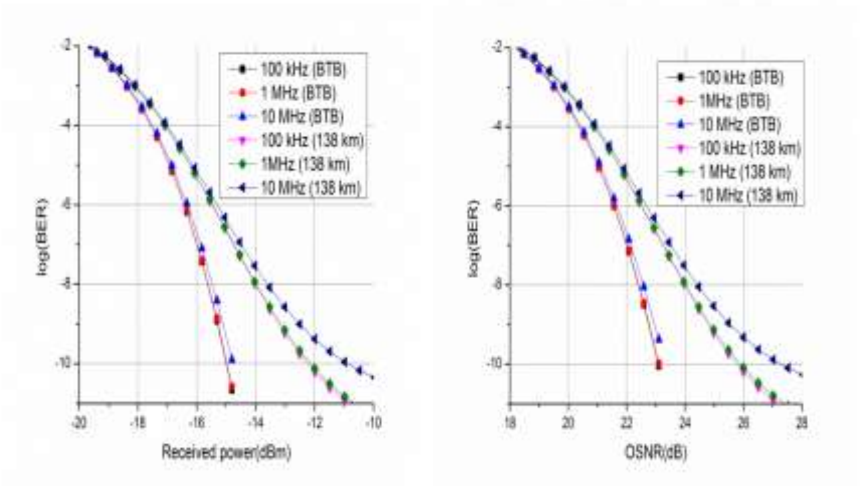
(ii) Q Branch (BTB)

(i) I Branch (138 km)

(ii) Q Branch (138 km**)**

Fig. 4: Eye diagrams of BTB and DQPSK payload after 138 km transmission: (a) i and ii are I and Q branch of BTB and (b) i and ii are I and Q branch of payload.

The reception quality of the payload is affected by the laser linewidth. In Fig. 5 (i) and (ii), for 100 kHz and 1 MHz laser linewidth cases, the bit error rate (BER) is smaller than the BER in a 10 MHz laser linewidth in both the BTB and 138 km transmission conditions for the same received optical power (ROP) and optical signal to noise ratio (OSNR). To achieve good transmission performance, system should operate with current conventional DFB lasers with a typical linewidth value in the order of up to 10 MHz.

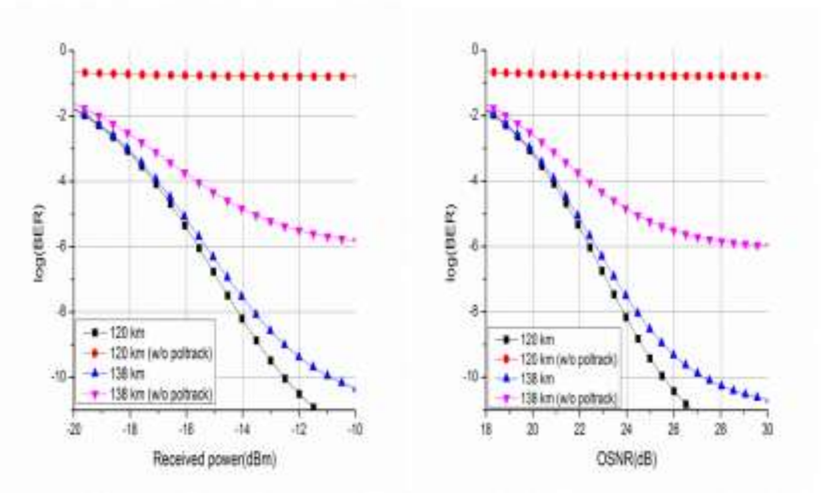


(i) (ii)

Fig. 5: Effects of payload's laser linewidth: (i) BER vs. ROP, (ii) BER vs. OSNR.

The frequency spacing between the payload and the labels likewise the frequency spacing between the labels should be considered so as to avoid correlation. Small frequency spacing can lead to interference which will damage the reception quality where wider frequency spacing will lead to waste of bandwidth. For the purpose of this simulation, frequency spacing of 40 G Hz is chosen between the payload and the labels while a frequency spacing of 5 GHz is chosen between labels.

Polarization effects due to interaction between polarization mode dispersion (PMD) and polarization dependent loss (PDL) can significantly impair optical fiber transmission systems. When PMD and PDL are both present, they interact. Polarization division multiplexing (PDM) system is very sensitive to both PMD and PDL effects. PMD produces a polarization state that varies randomly and a PDL which breaks the orthogonality of the two polarizations. This makes it hard for the signal to be demultiplexed. The polarization tracker is installed to repair the PMD and PDL impairments. This caused a power loss of less than 0.1 dB in our simulation. Fig. 6 shows the effects of polarization tracker on PMD.

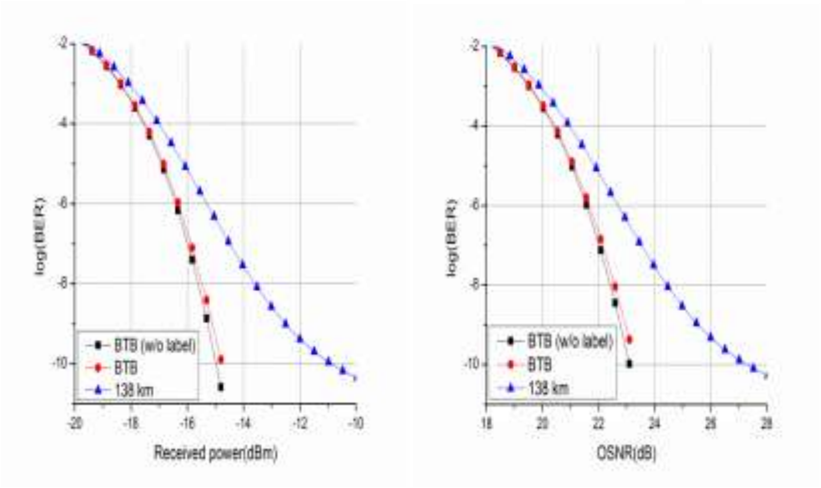


(a) (b)

Fig. 6: Effects of polarization tracker and PMD: (a) BER vs. ROP (b) BER vs. OSNR

As observed from Fig. 6 (a) and (b), without the polarization tracker, the signals cannot be demodulated due to PMD and PDL impairments. PMD impairment may cause some ROP and OSNR penalty.

The transmission performance of the payload is shown in Fig. 7 .The graph shows the transmission penalty for BTB with labels and without labels while the penalty for 138 km is compared to BTB with labels. The results of their performances are shown in Table I below;



(a) (b)

Fig. 7: Transmission performance of the payload: (a) BER vs. ROP (b) BER vs. OSNR.

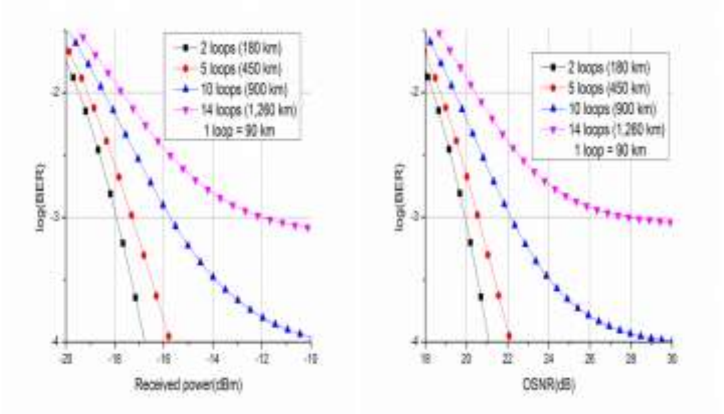
TABLE I: Transmission Penalty for Received Power and Optical Signal to Noise Ratio at BER 10^{-9}

Transmission	Received Power (dBm)		Optical Signal to Noise Ratio (dB)	
	Value	Penalty	Value	Penalty
BTB (without label)	-15.3		22.7	
BTB (with label)	-15.1	0.2	23.0	0.3
138 km	-12.6	2.5	25.6	2.6

Lastly, we examine and study long haul transmission by creating loop to study the performance of the system using forward error correction (FEC). The loop consisted of a standard single mode fiber (SSMF) of length 75 km and a dispersion compensation fiber (DCF) of length 15 km adding up to a total length of 90 km per loop bearing in mind each loop should not exceed 100 km. The loop also consisted of an EDFA to compensate the power loss. Using BER of 10^{-3} and forward error correction (FEC), a transmission distance of 1,260 km is achieved. The intensity dependent impairments are reduced automatically. The power gain margin can be used to increase the span of the optical link, which accounts for less number of amplifiers. The result is shown in Table II below.

TABLE II: Long Haul Transmission Using Forward Error Correction (FEC)

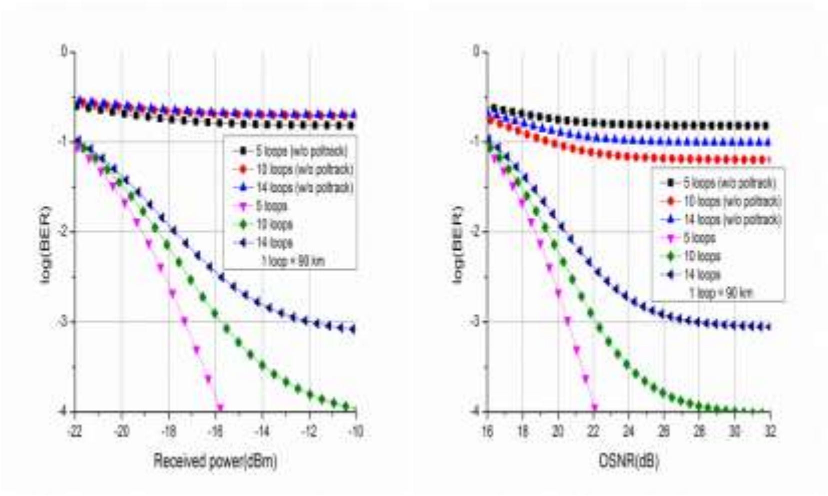
Distance (km)	BER	Received Power (dBm)	OSNR (dB)
180	10^{-3}	-17.93	19.94
450	10^{-3}	-17.30	20.57
900	10^{-3}	-15.74	22.18
1,260	10^{-3}	-11.90	27.67



(a) (b)

Fig. 8: Long haul transmission using forward error correction (FEC): (a) BER vs. ROP (b) BER vs. OSNR.

The effects of polarization tracker on PMD using loops and FEC are shown in Fig. 9.



(a) (b)

Fig. 9: Effects of polarization tracker and PMD using loops and FEC: (a) BER vs. ROP (b) BER vs OSNR

V. Conclusion

The performance and analysis of 80 Gb/s PDM-DQPSK transmission system with 4-bits 156 Mb/s SAC label is presented using computer simulation. The payload signal is demodulated using direct detection while the SAC label is detected using frequency-swept coherent detection. The polarization tracker in direct detection brings an insertion loss of less than 0.5 dB and a few watts of power consumption. The laser linewidth of the payload is optimized to 10 MHz. For BTB and 138 km transmission, the label EOF is 0.94 and 0.86 respectively. The payload's OSNR for BTB without label, BTB with label and after 138 km is 22.7, 23.0 and 25.6dB respectively. The payload's ROP for BTB without label, BTB with label and after 138 km is -15.3, -15.1 and -12.6 dBm respectively at a BER of 10^{-9}. A 1,260 km long haul transmission of the payload is also achieved using forward error correction (FEC) at a BER of 10^{-3}. This result indicates that the high speed payload and SAC label are compactible. The good performance of the system has potential application in future for all optical label switching.

Acknowledgement

The authors acknowledge the National Natural Science Foundation of China (61205067) for their support.

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