A 40 Gb/s Duty-Cycle/Polarization Division Multiplexing System

Kosar S. Dastgiri
Faculty of Electrical and Computer Engineering
University of Tabriz
Tabriz, Iran

Saleh Seyedzadeh,
Faculty of Engineering
University of Strathclyde
Glasgow, UK
Email: saleh.seyedzadeh@strath.ac.uk

Majid H. Kakaee
Department of Computer and Communication Systems Engineering,
Faculty of Engineering,
Universiti Putra Malaysia,
Selangor, Malaysia

***Abstract*—Ever increasing demand for higher bandwidth and capacity requests more efficient multiplexing techniques. Recently, hybrid optical systems have been developed in order to expand the capacity of optical networks. In this paper a combination of duty-cycle division multiplexing (DCDM) and polarization division multiplexing (PDM) system is proposed for long haul communication. In the proposed system each PDM channel carries 2-channel DCDM where each user is operating at data rate of 10 Gb/s which forms $2 \times 2 \times 10$ Gb/s optical system. Results show that the bit error rate of 10^{-9} for worst user is achieved at received power per chip of 21.12 dBm and optical signal to noise ratio of 22.08. Furthermore, system analysis demonstrates that the proposed system can tolerate the ± 10 ps/nm dispersion without any need for compensation.**

***Keywords*—Optical Communication, Hybrid Modulation, Polarization division multiplexing, Duty-cycle division multiplexing.**

I. Introduction

In order to satisfy the growing requirement of higher bandwidth, optical multiplexing techniques have been developed for better utilization of the high capacity of optical fibers. Several types of multiplexing techniques have been introduced such as polarization division multiplexing (PDM) [1], time division multiplexing (TDM) [2], wavelength division multiplexing (WDM) [3], [4]. Optical code division multiple access (OCDMA) system has been developed to share media among different users mostly in access and local area networks [5], [6].

Recently an electrical multiplexing technique named duty-cycle division multiplexing (DCDM), has been reported [7], [8]. In DCDM, return-to-zero (RZ) signals with different duty-cycles are used to provide multiple access [9]. DCDM supports n simultaneous users at single wavelength using $n+1$ time and n amplitude levels in each symbol period. There is only one rising per multiplexing symbol that is located at the beginning of the symbol. This makes the symbol synchronization of the system easier. Hence, despite TDM, the synchronization is much easier in DCDM system. Increasing the capacity of WDM system using DCDM for long haul optical communication [7] and using OCDMA system for last mile access [10] has been demonstrated. The proof of concept experiment of a DCDM receiver with an acceptable bit rate is demonstrated in [11].

PDM utilizes independent data sets on each of two orthogonal optical polarization states to double the total data throughput. Several optical systems based on polarization multiplexing have been reported such as time/polarization division multiplexing [12] and orthogonal frequency/polarization division multiplexing [13]. The successful high speed transmission of PDM is also demonstrated [14].

In this paper, a hybrid DCDM/PDM system is proposed to extend the capacity of PDM based optical network. The proposed technique combines electrical coding and optical multiplexing exploiting RZ signals. Here, users each transmitting at data rate of 10 Gb/s are electrically multiplexed and transmitted over PDM channels which forms a $2 \times 2 \times 10$ Gb/s system. The performance of users are expressed considering their bit error rate (BER) and eye diagram of received signal and optical signal to noise ratio (OSNR). Dispersion tolerance of proposed system is also presented.

The rest of this paper is organized as follows. In section II, the system architecture of hybrid DCDM/PDM system is explained in detail. In section III, the simulation results are demonstrated and BER of users are eventuated. Finally, the conclusion is presented in the forth section.

II. DCDM/PDM System Description

Fig. 1(a) and 1(b) show the possible combination of RZ signals with duty-cycles of $1/3T_s$ and $2/3T_s$ and eye diagram of back-to-back (B2B) 2-channel DCDM system, respectively, where T_s is the symbol duration. The last $1/3T_s$ slot per symbol is used as guard band which makes the synchronization much easier.

Fig. 2 shows the system setup for proposed hybrid DCDM/PDM system transmitting 2 users over one PDM channel. This setup is simulated using OptiSystem software and Matlab programming.

At the transmitter, the electrical signals of users with different duty-cycles are combined together using an electrical adder. The optical carriers is polarized into two different orthogonal states of polarization (SOPs) using a polarization splitter. The electrical signal from DCDM users are then modulated with optical carriers using a Mach-Zehnder modulator (MZM) to complete electro-optic conversion. The modulated signals of

978-1-5090-5963-8/17/$31.00

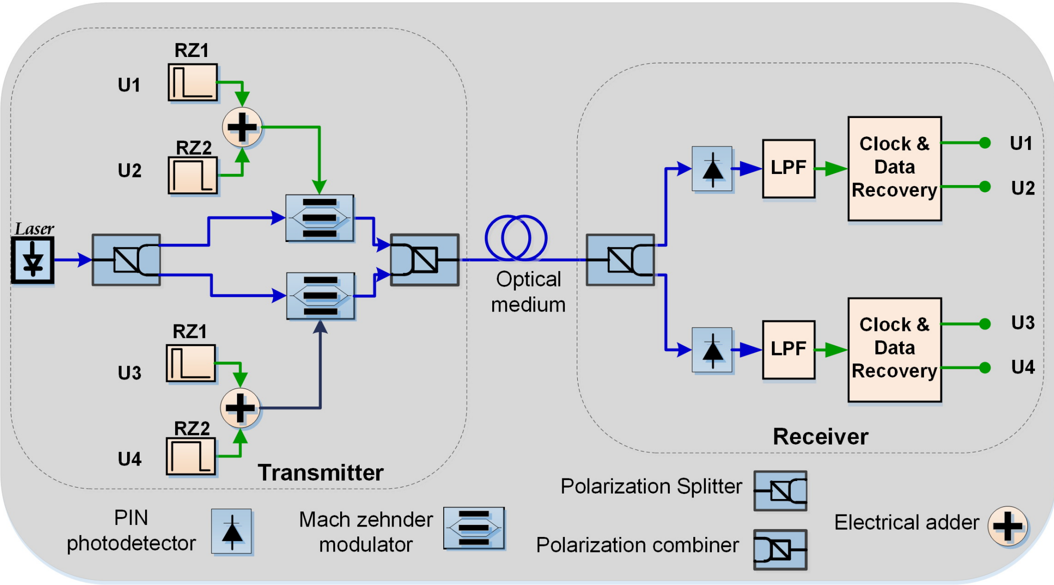
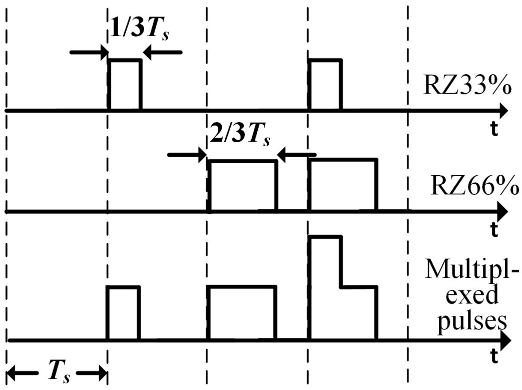
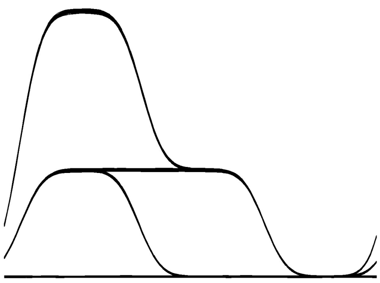


Fig. 2. Hybrid DCDM/OCDMA system setup with 2 DCDM and N OCDMA channels.



(a)



(b)

Fig. 1. (a) Possible combination of bits and (b) ideal eye pattern of a 2-channel DCDM system

different channels are then combined deploying a polarization beam combiner and transmitted over optical medium.

At the receiver side, a polarization beam splitter splits the modulated optical signals which are then converted to electric signals by a PIN photodiode. The electrical signal is then passed through a low pass filter (LPF) followed by DCDM demultiplexer. The BER of users are calculated using the same technique as [8].

In this research, the performance of B2B system is investigated as BER of users by varying the received optical power (ROP) and OSNR of retrieved signals. Each user in the system is operating at data rate of 10 Gb/s ($2 \times 2 \times 10$ Gb/s hybrid DCDM/PDM system).

III. Results and Discussion

Fig. 3 shows the BER of the worst users for B2B system with two users per PDM channel versus OSNR of received signal. It can be seen that Considering the worst user, the BER of 10^{-9} is obtained at OSNR of 22.08 dB, this shows 2.3 dB improvement comparing to normal DCDM in which BER of 10^{-9} is attained at OSNR of 24.11 dB [15].

Performance of proposed system is also investigated by varying the received power. As the power of different wavelength may vary due to modulation, the average received power of all channels is considered. The log of BER for worst user against average received optical power per chip is illustrated in Fig. 4. With reference to BER of 10^{-9}, minimum received optical power of -21.12 dBm is required for each chip in a B2B system.

Fig. 5 presents the eye diagram of worst channel at BER of 10^{-9}. The Q-factor values are 7.18, 5.43 and 5.87 for Q_1, Q_2 and Q_3, respectively.

Fig. 6 shows the effect of chromatic dispersion on the performance of proposed system. All users show almost similar behavior at positive and negative chromatic dispersions. Users with duty cycles of 33% and 66% can tolerate chromatic dispersion of $\pm$101 and $\pm$103.5 ps/nm at BER of 10^{-9}, respectively.

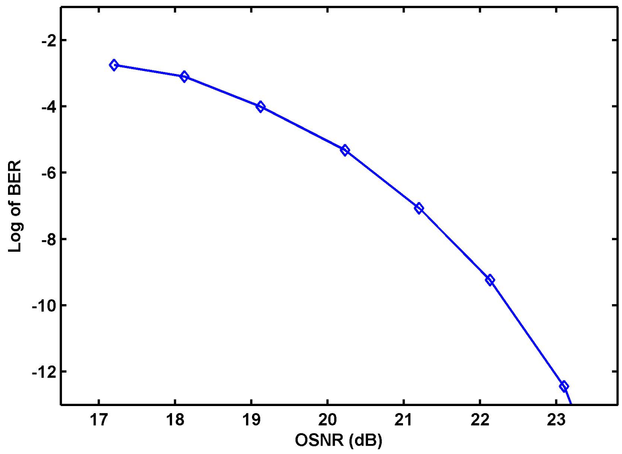


Fig. 3. Log BER against average optical SNR.

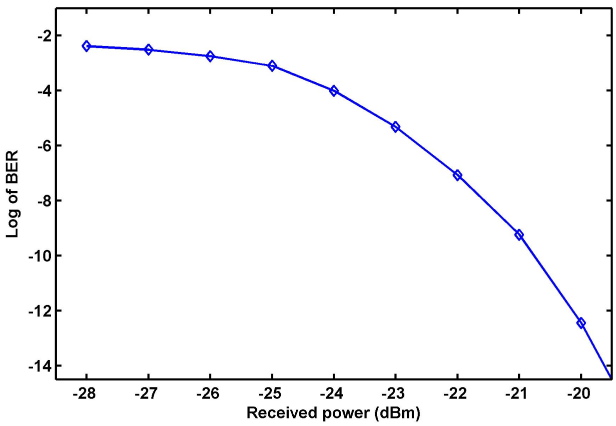


Fig. 4. Log of BER versus average received optical power per chip.

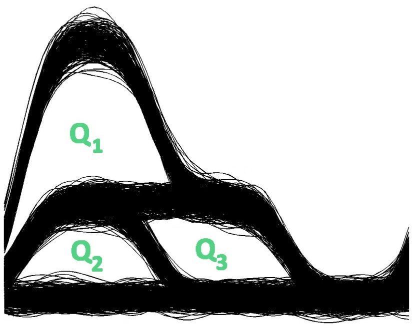


Fig. 5. Eye diagram of worst DCDM/PDM user at BER of 10^{-9}.

These results indicate that proposed DCDM/PDM system is more robust to dispersion in comparison with conventional 4-channel DCDM which tolerates approximately 95 ps/nm of

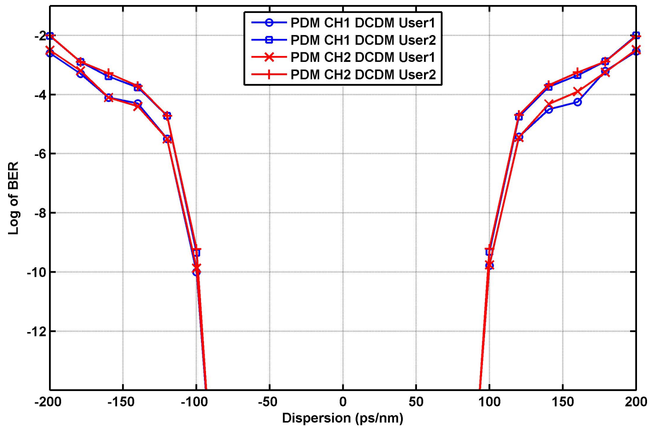


Fig. 6. Log of BER versus average received optical power per chip for the system operating at data rate of 20 Gb/s.

dispersion [16].

In order to evaluate the DCDM/PDM system a comparison with other multi-bits/symbol systems such as 8-level phase-shift keying (8-DPSK) and amplitude-/differential phase-shift keying (ASK-DPSK) [17], [18] is represented. Table I demonstrates and compares the performance of the different modulation formats at bitrate of 40 Gbps. Both 8-DPSK and ASK-DQPSK have better dispersion tolerance compare to DCDM/PDM. Required OSNR for DCDM is 1.5 and 0.7 dB higeher than for RZ and NRZ ASK-DQPSK, respectively. DCDM requires 5 and 6.2 dB lower OSNR comparing to RZ and NRZ 8-DPSK, respectively. In general, ASK-DQPSK with RZ signals shows the best tolerability to dispersion and receiver sensitivity. In term of transmitter and receiver complexity, DCDM/PDM outperforms other systems, where two MZM and photo detector (PD) and three polarization combiners is the required optical components at the transmitter and receiver, respectively. 8-DPSK needs two MZM, one phase modulator (PM) and one phase shift (PS) component only at the transmitter and four PDs and two delay and add filters at the receiver. The receiver of ASK-DQPSK system is even more complex than 8-DPSk.

IV. Conclusion

In this research work a novel hybrid multiplexing technique based on DCDM and PDM systems was proposed. A $2 \times 2 \times 10$ Gb/s DCDM/PDM system was investigated using simulation model. The performance of system was investigated as log of BER of worst user by varying the average received power per chip and average OSNR of 4 channels. In addition it was shown that the minimum average received power of -21.12 dBm is needed to maintain the BER of 10^{-9} and the same BER is attained at OSNR of 22.08 dB. Compared with the pure DCDM system carrying 4 users DCDM/PDM has shown noticeable improvement in term of OSNR of received signal. Eye diagram and Q-factor of worst channel at BER of 10^{-9} were also illustrated. In this research, it has been shown that the dispersion tolerance of proposed hybrid system is around 102 ps/nm. The main advantage of proposed system is that the capacity of existing PDM systems could be increased without any need

TABLE I. COMPARISON BETWEEN DIFFERENT SYSTEMS OPERATING AT DATA RATE OF 40 GBPS

Modulation Format	Complexity	Sensitivity (dBm)	Dispersion tolerance (ps/nm)
NRZ 8-DPSK	2 MZM, 1 PM, 1 PS, 1 coupler, 4 PD, 2 delay & add filter, 1 coupler	28.2	177
RZ 8-DPSK		27	368
NRZ ASK-DQPSK	2 MZM, 1 PM, 1 PS, 5 PD, 2 delay lines, 2 PD & add filter, 1 Gussian bandpass filter	21.3	226
RZ ASK-DQPSK		20.5	165
DCDM/PDM	3 Polarization combiner, 2MZM, 2PD	22	104

for modifying the optical system, for DCDM encode/decodes in electrical domain and it can be implemented using logic gates [19]. The capacity of DCDM/PDM system itself can be increased either electrically or optically. In electrical domain which is much economical, DCDM system with higher channels (e.g. 3 or 4-channels) could be employed. On the other hand, combination of DCDM/PDM and WDM system will allow to vastly extend the number of users. Based on the properties of the proposed system, it is an alternative solution for long haul optical communication. Further improvements of DCDM/PDM system can be achieved by controlling the amplitude distribution of different levels.

REFERENCES

[1] P. Hill, R. Olshansky, and W. Burns, "Optical polarization division multiplexing at 4 Gb/s," *IEEE Photonics Technology Letters*, vol. 4, pp. 500–502, may 1992.

[2] A. Mozer, "Optical time-division multiplexing," jul 1994.

[3] J. Sakaguchi, B. J. Puttnam, W. Klaus, Y. Awaji, N. Wada, A. Kanno, T. Kawanishi, K. Imamura, H. Inaba, K. Mukasa, R. Sugizaki, T. Kobayashi, and M. Watanabe, "19-core fiber transmission of 19x100x172-Gb/s SDM-WDM-PDM-QPSK signals at 305Tb/s," in *National Fiber Optic Engineers Conference*, (Washington, D.C.), p. PDP5C.1, OSA, 2012.

[4] H. Chung and Y. Chung, "Transmission of 40Gb/s8 WDM channels with 100GHz spacing using short-period dispersion-managed fiber," *Optics Communications*, vol. 250, no. 4, pp. 286–291, 2005.

[5] S. Seyedzadeh, G. A. Mahdiraji, R. K. Z. Sahbudin, A. F. Abas, and S. B. A. Anas, "Experimental demonstration of variable weight SAC-OCDMA system for QoS differentiation," *Optical Fiber Technology*, jul 2014.

[6] S. Seyedzadeh and M. Moghaddasi, "Variable-Weight Optical Code Division Multiple Access System using Different Detection Schemes," *Journal of Telecommunications and Information Technology*, vol. 3, pp. 50–59, 2016.

[7] S. Seyedzadeh, G. Amouzad Mahdiraji, and A. F. Abas, "Performance Analysis of Duty-Cycle Division Multiplexing over Wavelength Division Multiplexing System," *Fiber and Integrated Optics*, vol. 33, no. 3, pp. 232–250, 2014.

[8] G. A. Mahdiraji, M. K. Abdullah, M. Mokhtar, A. Malekmohammadi, and A. F. Abas, "Duty-cycle-division-multiplexing: Bit error rate estimation and performance evaluation," *Optical Review*, vol. 16, pp. 422–425, jun 2009.

[9] G. Amouzad Mahdiraji and A. F. Abas, "Improving the performance of electrical duty-cycle division multiplexing with optimum signal level spacing," *Optics Communications*, vol. 285, pp. 1819–1824, apr 2012.

[10] S. Seyedzadeh, G. A. Mahdiraji, Y. G. Shee, and F. R. M. Adikan, "A Novel Asynchronous Hybrid Duty-Cycle Division Multiplexing/Optical Code Division Multiple Access Systeme," in *International symposium on Telecommunications*, (Tehran), 2014.

[11] S. M. Basir, G. Mahdiraji, A. Malekmohammadi, A. Ibrahim, A. Abas, M. Abdullah, N. Mohamed, and S. Idrus, "Proof-of-Concept Experiment of Duty Cycle Division Multiplexing with Bit Error Rate Analysis," *Open Electrical & Electronic Engineering Journal*, vol. 6, pp. 1–6, 2012.

[12] K. Iwatsuki, K. Suzuki, and S. Nishi, "80 Gb/s optical soliton transmission over 80 km with time/polarization division multiplexing," *IEEE photonics*, 1993.

[13] S. Jansen, I. Morita, and T. Schenk, "121.9-Gb/s PDM-OFDM transmission with 2-b/s/Hz spectral efficiency over 1000 km of SSMF," *Journal of Lightwave*, 2009.

[14] J. Li, C. Zhao, S. Zhang, and F. Zhang, "Experimental demonstration of 120-Gb/s PDM CO-SCFDE transmission over 317-km SSMF," *IEEE Photonics*, 2010.

[15] S. Seyedzadeh and G. A. Mahdiraji, "A new signal combination for 3-channel duty-cycle division multiplexing technique," in *2014 IEEE 5th International Conference on Photonics (ICP)*, pp. 23–25, IEEE, sep 2014.

[16] G. Mahdiraji, M. Abdullah, A. Mohammadi, A. Abas, M. Mokhtar, and E. Zahedi, "Duty-cycle division multiplexing (DCDM)," *Optics & Laser Technology*, vol. 42, pp. 289–295, mar 2010.

[17] M. Ohm and J. Speidel, "Optimal Receiver Bandwidths, Bit Error Probabilities and Chromatic Dispersion Tolerance of 40 Gbit/s Optical 8-DPSK with NRZ and RZ Impulse Shaping - Technical Digest (CD)," in *Optical Fiber Communication Conference and Exposition and The National Fiber Optic Engineers Conference*, (Anaheim, California), p. OFG5, Optical Society of America, 2005.

[18] M. Ohm and J. Speidel, "Receiver sensitivity, chromatic dispersion tolerance and optimal receiver bandwidths for 40 Gbit/s 8-level optical ASK-DQPSK and optical 8-DPSK," *6th Conference on Photonic Networks*, pp. 211–217, 2005.

[19] A. Malekmohammadi and M. K. Abdullah, "Experimental demonstration of Absolute Polar Duty Cycle Division Multiplexing," in *International Conference on Signal Processing and Communication Systems*, (Barcelona), pp. 1–5, IEEE, dec 2012.