20 Gb/s Absolute Polar Duty Cycle Division Multiplexing-Polarization Division Multiplexing (AP-DCDM-PolDM) Transmission System

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***Abstract*— The performance of Absolute Polar Duty Cycle Division Multiplexing (AP-DCDM) over Polarization Division Multiplexing (PolDM) system is presented based on the simulation results, in order to double the capacity in optical fiber links. It is demonstrated that the spectral width occupied by 10 Gb/s RZ is 40 GHz whereas, this value can be reduced to 20 GHz over 2 channels of the proposed system. Simulations show that the maximum attainable dispersion-limited transmission distance for 20-Gb/s AP-DCDM-PolDM data over standard single-mode fiber can be extended to 200 km for a 2-dB penalty.**

Keywords- Optical Communication; AP-DCDM; PolDM

I. INTRODUCTION

There has recently been a capacity explosion of optical fiber links due to techniques such as Wavelength-Division Multiplexing (WDM) [1]. However, WDM systems are straining to accommodate either smaller channel wavelength spacing or wider wavelength ranges in order to continue the growth in capacity. The minimum channel spacing and the total wavelength range are limited by many factors, including optical filters, wavelength drifts, signal bandwidth, Erbium-Doped Fiber Amplifier (EDFA) bandwidth, and dispersion and nonlinearities [1, 2].

Next generation systems working at 40-Gb/s data rates and incorporating Dense Wavelength-Division Multiplexing (DWDM) will require bandwidth efficient transmission formats to minimize the chromatic dispersion penalty [3]. Bandwidth efficiency is also important for maximizing the spectral efficiency of the WDM transmitters, whilst maintaining low levels of crosstalk. Bandwidth efficient transmission has previously been achieved in several ways including advanced modulation formats such as Differential Quadrature Phase Shift Keying (DQPSK) However, this technique increase the complexity of the receiver by the introduction of the temperature-stabilized Mach-Zehnder Interferometer (MZI) [4].

Absolute Polar Duty Cycle Division Multiplexing (AP-DCDM) is an alternative multiplexing which appears promising for its spectral width and its chromatic dispersion tolerance [5, 6]. The narrow optical spectrum on AP-DCDM reduces the inter channel coherent crosstalk in AP-DCDM-WDM systems. The possibility of setting channel spacing as narrow as 62.5 GHz for 40 Gbit/s AP-DCDM signals over WDM was confirmed [6]. As reported in [6], a capacity of 1.28 Tbit/s (32 x 40 Gbit/s) was packed into a 15.5 nm EDFA gain-band with 0.64 bit/s/Hz spectral efficiency by using 10 Gbit/s transmitter and receiver. Good propagation format together with a simple transmitter implementation make AP-DCDM very interesting for uncompensated optical links [5].

Polarization Division Multiplexing (PolDM) is well known technique for doubling the spectral efficiency. In PolDM system two signals are transmitted at the same wavelength with orthogonal States of Polarization (SOP). At the receiving end the polarization channels are demultiplexed at polarization beam splitter and detected independently. PolDM allows the transmission at an equivalent double bitrate without reducing the reach to a fourth due to chromatic dispersion [7, 8]. PolDM has the advantage that it can be implemented without major changes to the existing systems. PolDM can be implemented by adding a transceiver and associated polarization multiplexer/demultiplexer at each end of the fiber link, while leaving the rest of the system unchanged [9].

In this paper, for the first time to the best of our knowledge, the AP-DCDM system has been exploited together with PolDM in order to achieve, a reach of 200 km at an overall bitrate of 20 Gb/s (2 x 2 x 5 Gb/s), without dispersion compensation.

This paper is organized as follows. Section II describes the simulation setup of AP-DCDM-PolDM over 200 km single mode fiber. Section III discusses the implementation issues in comparison against other techniques and Section IV discusses the performance of AP-DCDM over PolDM.

II. SIMULATION SETUP

In this study, two commercial software, OptiSystem and MATLAB were used to access the system performance. The performance evaluation of the system is based on Bit Error Rate (BER) which is described in [5].

Fig.1 shows the model of AP-DCDM over PolDM system. The evaluation starts with 2 AP-DCDM channels setup. Data1, Data 2, each at 5 Gb/s with Pseudo Random Binary Sequence (PRBS) of 2^{10} -1 are carved with one electrical RZ pulse carvers at 50% of duty cycle and NRZ pulse carver, respectively.

The voltages for all users at the multiplexer input are identical. All users' data are multiplexed via a power combiner (electrical adder) resulting in a bipolar signal. Subsequently, the absolute circuit is used to produce an absolute polar signal [5]. The signals are used to modulate a Laser Diode (LD), which operates at 1550 nm wavelength using a Mach-Zehnder Modulator (MZM). The modulated AP-DCDM signal is split in two replicas uncorrelated by means of a fiber spoil, with a delay of about 15 µs.

The two replicas, equalized in power, are orthogonally polarized by adjustable fiber Polarization Controller (PC) and recombined by a pig-tailed micro-optic Polarization Beam Combiner (PBC).

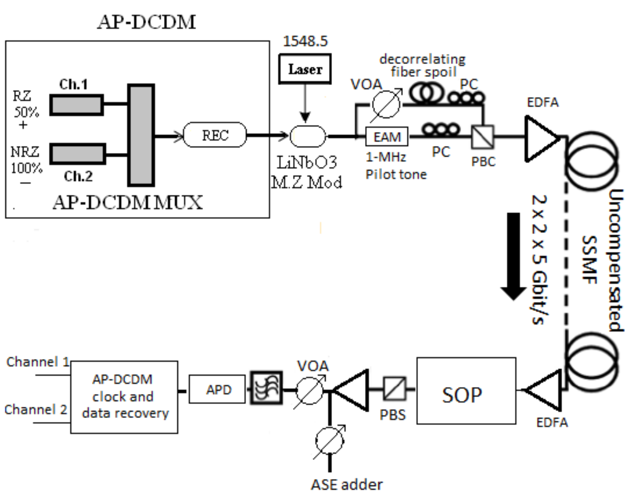

Figure 1. AP-DCDM-PDM Setup

A polarization multiplexed signal at an overall bit-rate of 20 Gb/s is generated and then it is boosted by an Erbium-Doped Fiber Amplifier (EDFA) and launched in a uncompensated Single Mode Fiber (SMF) link. At the receiver, the multiplexed channels are optically preamplified by an EDFA and a variable amount of Amplified Spontaneous Emission (ASE) noise, generated by a filtered ASE source, is added in order to modify the Optical Signal-to-Noise Ratio (OSNR).

The 20 Gb/s AP-DCDM-PolDM performance is assessed over lengths ranging from back-to-back to 200 km. nonlinear effects are negligible due to low lunch power [10, 11].

At the end of the fiber link, the two orthogonally polarized PolDM channels at the same wavelength are then optically demultiplexed by a fiber Polarization Beam Splitter (PBS) after an adjustable fiber PC.

A single demultiplexed channel is detected by a Avalanche Photodiode (APD) and passed through a Low-Pass Filter (LPF) and a Clock-and-Data-Recovery (CDR) unit. The regeneration and error detector are programmed, using sampling points and threshold value. The samples are taken at two sampling points (S_1 and S_2) at the first two slots in every symbol [5]. The sample values are fed into the decision and regeneration program. In this program, the sampled values are compared against threshold value and the decision is performed based on the operation shown in Tables I and II [5, 6]. These tables contain the regeneration rules for a two-channel AP-DCDM system that the data recovery program uses to regenerate original data for each channel. For example for user one, binary 0 is regenerated when sampling values at S_1 and S_2 are less than threshold value (Table 1 rule 1). Binary 1 is regenerated when sampled amplitude at S_1 is equal or greater than threshold, while amplitude at S_2 is less than threshold (Table 1 rule 3) [5].

TABLE I. DATA RECOVERY RULES FOR USER 1 (U1)

No	Rules					
1	if	(S_1 < Thr)	&	(S_2 < Thr)	then	U1 = 0
2	if	($S_1 \geq$ Thr)	&	($S_2 \geq$ Thr)	then	U1 = 0
3	if	($S_1 \geq$ Thr)	&	(S_2 < Thr)	then	U1 = 1
4	if	(S_1 < Thr)	&	($S_2 \geq$ Thr)	then	U1 = 1

TABLE II DATA RECOVERY RULES FOR USER 2 (U2)

No	Rules			
1	if	(S_2 < Thr)	then	U2 = 0
2	if	($S_2 \geq$ Thr)	then	U2 = 1

III. IMPLEMENTATION ISSUES IN COMPARISON WITH OTHER TECHNIQUES

AP-DCDM like NRZ-OOK requires only one Modulator and one Photodiode (PD) for n number of users at the transmitter and the receiver side, respectively. This is very economical in comparison to other modulation formats such as NRZ-DPSK, which require one Delay Interferometer (DI) and two PDs at the receiver [5], or RZ-DQPSK which requires two MZM at the transmitter, and two DIs together with four PDs at the receiver [5] or duobinary which require one dual-arm MZM modulator including driver amplifier for each modulator arm at the transmitter and one PD in the receiver.

Referring to the AP-DCDM data recovery concept, one may argue that the complexity of AP-DCDM receiver is higher than other systems. However, the complexity is due to additional electronics components and devices, the solutions of which are available in term of technology and experts [5].

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IV. PERFORMANCE OF AP-DCDM-POLDM

Fig. 2 shows the optical spectra measured after the MZM. Considering the null–to–null bandwidth, the spectral width of 10 Gb/s AP-DCDM is around 20 GHz and it is equivalent to that of a 10 Gb/s NRZ-OOK signal. Comparing the optical spectral width at the same aggregate bit rate (10 Gb/s) between RZ-OOK (which is around 40 GHz), and AP-DCDM, AP-DCDM shows a great spectral width reduction (~20 GHz). This is because AP-DCDM divides the symbol to n slots where n is the number of channels [5]. Thus, it requires a null-to-null spectral width of 2 × [n × single channel bit rate], whereas RZ-OOK requires 2 × (2 × aggregate bit rate). This amount of saving in the spectral width is will leads to better spectral efficiency and tolerance to chromatic dispersion [5].

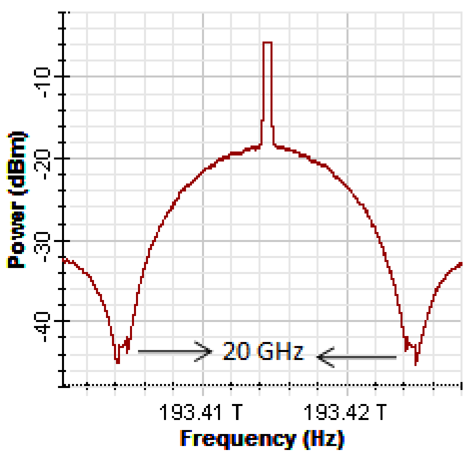

Figure 2. Optical spectra for AP-DCDM

The PolDM-AP-DCDM system at 20 Gb/s with the SOP stabilizer is tested for different SSMF propagation lengths up to 200 km. we have measured the BER as a function of the single demultiplexed channel OSNR, which is detected after polarization demultiplexing. Note that the optical power at the APD input is kept constant to -15 dBm. The performance of the PolDM-AP-DCDM transmission is compared with single channel transmission. Fig. 3 shows the required OSNR for a BER value of 10^{-9} versus propagation length. In the case of back to back because of the around 35 dB polarization extinction ratios of both polarization beam combiner and polarization beam splitter and to the good constancy of the SOP at the demultiplexing polarization beam splitter there is no penalty in transitory from the case of single channel transmission to the case of both polarization multiplexed channels. The cross-talk between the channels after polarization demultiplexing is thus small therefore with respect to the single channel case the penalty is negligible.

On the other hand in correspondence of the BER measurements for propagation length of around 70 km and more a penalty is found due to the cross-talk which is generated by small SOP fluctuations and enhanced by the fiber propagation, at the polarization beam splitter after polarization demultiplexing.

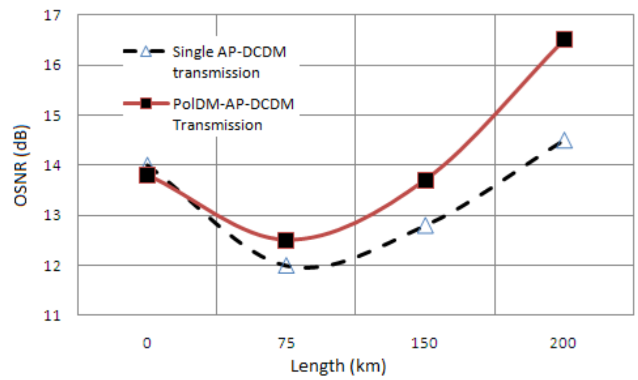

Figure 3. OSNR for a BER of 10^{-9} versus length of propagation over uncompensated SMF

In the case below, 150 km refer to the channel whose performance is slightly worse than the orthogonally polarized channel. the penalties remain however not higher than 1 dB but at 200 km OSNR penalty increases to around 2 dB and a change in the slope is obvious as can be seen in Figure 4, where BER carve versus OSNR are shown.

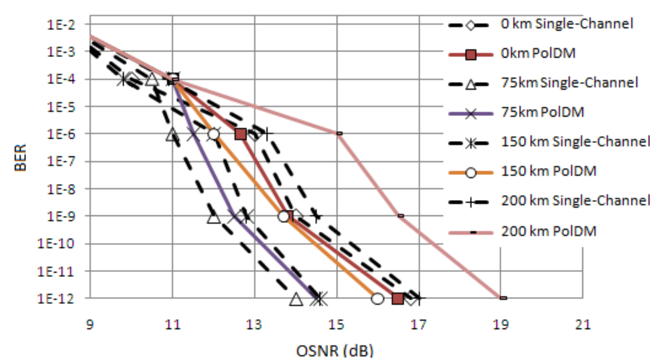

Figure 4. BER curves versus OSNR for different length of propagation over uncompensated SMF

V. CONCLUSION

Absolute Polar Duty Cycle Division Multiplexing over Polarization Division Multiplexing has been proved an attractive technique to double the transmission rate, while preserving the 10 Gb/s dispersion tolerance of the AP-DCDM format. The numerical results confirm that using this electrical multiplexing/demultiplexing technique, more than two users can be carried over the same PolDM channel. Consequently, the capacity

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utilization of the PolDM channels can be increased tremendously; which is achieved at a lower spectral width in comparison to conventional techniques. Transmission over 200 km SSMF was also demonstrated. Based on the simulation results it can be concluded that AP-DCDM is suitable for implementation in PolDM transmission systems.

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