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Abstract

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Investigation of low code rate DP-8PSK as an alternative to DP-QPSK

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Abstract: Low code rate DP-8PSK was studied as an alternative to DP-QPSK for long distance coherent communications. For 4,000 km transmission with multiple link configurations, low code rate DP-8PSK is shown to have $1.6-1.8$ dB span loss budget over DP-QPSK for the same spectral efficiency through simulations.

OCIS codes: (060.4510) Optical communications, (060.1660) Coherent communications, (060.4080) Modulation.

1. Introduction

Recently, in order to predict the soft-decision decoding performances of modulation formats for bit-interleaved coded modulation (BICM) systems, generalized mutual information (GMI) is being used [1–3]. For coherent optical communications, dual polarization quadrature phase-shift keying (DP-QPSK) is the most widely used modulation format for wide range of transmission distances. In order to further improve the performance for the same spectral efficiency, subset-optimized polarization multiplexed (SO-PM) QPSK was proposed [4], which showed some gain in pre-FEC bit error ratio (BER), but not in GMI [1]. $1,000$ km transmission of 8 state trellis coded modulation employing 8PSK was experimentally shown to have 0.4 dB gain over QPSK of the same date rate at a pre-FEC BER, however, GMI has not been reported and its benefit for BICM systems with SD-FEC is unknown [5].
Recently, DP-QPSK, DP-16QAM, DP-64QAM, DP-256QAM with varying degrees of code rates have been studied to achieve the highest GMI at a given signal to noise ratio (SNR) [6]. Another study explored a total of 10 modulation formats to find the best combination of spectral efficiency and highest span loss budget [7]. In this paper, we report the nonlinear transmission performance of low code rate DP-8PSK and compare that of a high code rate DP-QPSK with the same information bit rate. Since DP-8PSK is generally more susceptible to phase noise and cycle slip compared to DP-QPSK of the same code rate, we investigate low code rate 8PSK using a constant modulus algorithm (CMA) equalizer and a recently-developed multi-pilot aided carrier phase estimator (CPE) [8].

2. AWGN Channel Performance

We first calculate GMI of the several modulation formats for AWGN channels as shown in Fig. 1. The procedure for calculating GMI is described in [1]. Here, we chose the normalized GMI of 0.85 as the target [2] for the state-of-the-art SD-FEC of a code rate 0.8 [9]. This corresponds to a GMI $=3.4$ bits/symbol for DP-QPSK. In order to achieve the same spectral efficiency, we use the same target for other modulation formats. Among the three 6 b/s/Hz modulation formats (code rate $=0.533$ and normalized target GMI $=0.567$), DP-8PSK shows the lowest required SNR at GMI $=3.4$ bits/symbol. 4D-2A8PSK [10], which has higher GMI than DP-8PSK and DP-Star-8QAM at target GMI >4.5, have higher required SNR than DP-8PSK at GMI $=3.4$. The gain in SNR of 8PSK over QPSK is 0.7 dB, while the extra required SNR gain of DP-16QAM over 8PSK is 0.2 dB. Considering that DP-16QAM offer relatively small incremental reduction in required SNR and the implementation complexity is much higher (code rate $=0.4$), we focus on the comparison of DP-8PSK and DP-QPSK in the following transmission simulations.

3. Optical Transmission Simulation Procedure

We simulated transmission performance over three types of 4,000 km links at a rate of 34 GBd per wavelength to investigate the effect of different level of fiber nonlinearity: 1) Uncompensated (UC) standard single mode fiber (SSMF), 2) dispersion managed (DM) SSMF, and 3) DM non-zero dispersion shifted fiber (NZDSF). DP-8PSK and DP-QPSK were used as the modulation formats. At the transmitter, impulse signals were filtered by a root-raised-cosine (RRC) filter with a roll-off factor of 0.1, which drives an ideal I/Q modulator. 11-wavelength channels with the same code

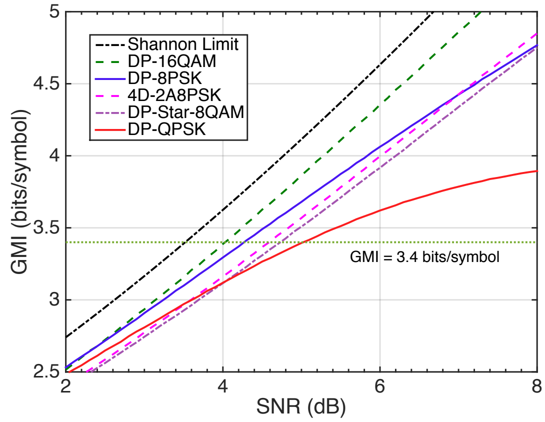

Fig. 1: GMI of the five modulation formats as a function of SNR.

were simulated with 37.5 GHz spacing and no optical filtering. The link comprises of 50 spans of 80 km fiber with loss compensated by Erbium-doped fiber amplifiers (EDFAs). In order to quantify performance over a single link for multiple modulation formats, span loss budget was used as a performance metric [11]. SSMF parameters were, $\gamma = 1.2$ /W/km; D = 17 ps/nm/km; α = 0.2 dB/km. NZDSF parameters were, $\gamma = 1.6$ /W/km; D = 3.9 ps/nm/km; α = 0.2 dB/km. In the case of DM links, 90% of the chromatic dispersion was compensated as a lumped linear dispersion compensator at the end of each span. We used Manakov equations to model the nonlinear fiber transmission. Other fiber effects such as dispersion slope and polarization mode dispersion were not simulated. 50% of the residual dispersion was introduced as pre-compensation. All the optical noise due to the EDFA (5.0 dB noise figure) and phase noise of $\Delta \nu T_s$ = 2e-5 (corresponding to 680 kHz for the combined transmitter and local oscillator lasers) were loaded just before the receiver. An ideal homodyne coherent receiver was used, with a transfer function described by the RRC filter of a roll-off factor of 0.1, followed by sampling at twice the symbol rate. Following this, ideal chromatic dispersion equalization, a standard 15-tap CMA equalizer, and a multi-pilot aided CPE [8] were used. The pilot insertion ratio (PIR) was 1%. The phases of x- and y-polarizations were jointly estimated assuming the correlation coefficient of 0.7. By adjusting the optical signal-to-noise ratio (OSNR) level to match the target GMI, we calculate the required OSNR (ROSNR), and then calculate the span loss budget.

4. Simulation Results

The plot of span loss budget vs. launch power for DP-8PSK and DP-QPSK are given in Fig. 2. For each link configuration, at low launch power, low rate DP-8PSK outperforms high code rate DP-QPSK by $0.7-0.8$ dB. In the nonlinear region, the difference becomes larger, reaching $1.6, 1.8$, and 1.7 dB for the UC-SSMF, DM-SSMF, DM-NZDSF links, respectively. This can be qualitatively explained as follows. DP-8PSK is Gray-coded, so noise first causes log-likelihood ratio (LLR) for one of the bit to be greatly affected. However, due to the low code rate, there is enough redundancy to recover the correct information.

Additionally, we evaluated the ROSNR as a function of pilot insertion rate (PIR) for the NZDSF link as shown in Fig. 3. Here, we used the fiber launch power of -4 dBm for the NZDSF link, which is near the peak of the span loss budget in Fig. 2. Even though ROSNR increases with lower PIR, low code rate DP-8PSK always performed better than DP-QPSK for the same PIR. This indicates that low code rate DP-8PSK is less susceptible to phase noise, due to the extra redundancy. It should be noted that cycle slips could not be observed in the parameter range in Fig. 3. With lower PIR and OSNR, cycle slips were sometimes observed, and GMI went down. Therefore, it is still important to choose a very good CPE algorithm and adequate PIR to minimize cycle slips.

The good nonlinear performance also comes from the fact that DP-8PSK is a constant modulus modulation format, compared to other modulation formats (such as DP-Star-8QAM) where power levels vary [3].

These results indicate that low code rate DP-8PSK can be an alternative to a standard high code rate DP-QPSK.

5. Conclusion

Through nonlinear fiber transmission simulations, we compared low code rate DP-8PSK and high code DP-QPSK for the same information bit rate. Laser linewidth effect, standard CMA, and multi-pilot CPE were included in the

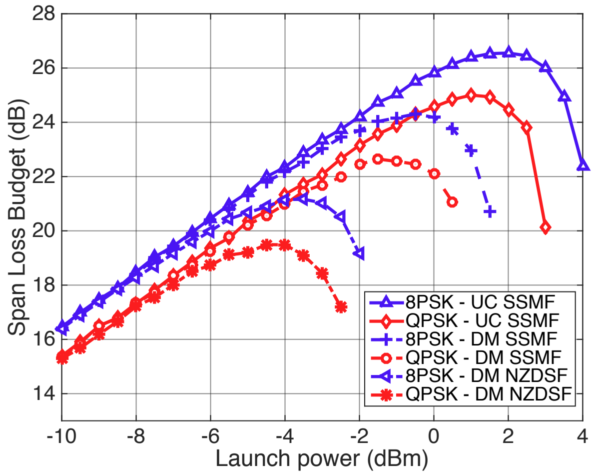

Fig. 2: Span loss budget of low code rate 8PSK and high code rate QPSK of the same information bit rate, plotted as a function of launch power for three types of links.

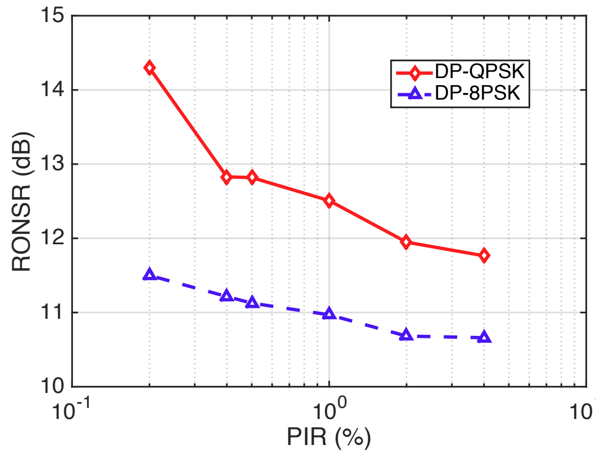

Fig. 3: Required OSNR as a function of PIR for the DM-NZDSF link with fiber launch power at -4 dBm.

simulation. We determined that low code rate 8PSK has $1.6-1.8$ dB advantage over high code rate DP-QPSK. It is also less sensitive to pilot insertion ratio.

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