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1. Introduction

Fiber nonlinearity is usually the limiting factor in determining the transmission distance of optical communications. One of the ways to mitigate fiber nonlinearity is to use multi-subcarrier (MSC) modulation. It has been theoretically and experimentally demonstrated that MSC modulation comprising of 2-4 GBd subcarriers is the best in terms of nonlinearity tolerance [1–3]. This is due to the fact that coherence among subcarriers decreases with narrower subcarriers. Four-dimensional (4D) constant modulus modulation formats have also been shown to have nonlinenearity tolerance compared to conventional modulation formats in the conventional 31-34 GBd wavelength domain multiplexed (WDM) channels [4]. 4D constant modulus format was recently applied to MCS, and it was confirmed that both work very well together [5].

Mapping 4D constant modulus signal comprising two complementary amplitude signals onto dual polarization optical signal has multiple options. In particular, in the case of MSC, using two neighboring subcarriers becomes a viable option, since they can be generated from a single transmitter. In this paper, through nonlinear transmission simulations using a dispersion unmanaged link, we show that 4D constant modulus modulation formats retain the nonlinearity-tolerance, for all three options we considered.

2. Modulation format and simulation procedure

For the evaluation of the modulation formats, we use generalized mutual information (GMI) as a metric for bit-interleaved coded modulation (BICM) systems. We chose the normalized GMI of 0.86.

The MCS configuration is similar to Ref. 5. Each subcarrier is modulated with 32, 16, ..., 1 GBd with root raised cosine (RRC) filter with a roll-off parameter of 0.01. Subcarrier channel spacing is 1.01 times the baud rate. The total number of subcarriers are chosen as 8, 16, ..., 256, such that the total bandwidth is identical. We used 1/4 of the subcarriers near the center just like in Ref. 5 to calculate the average GMI of the signal.

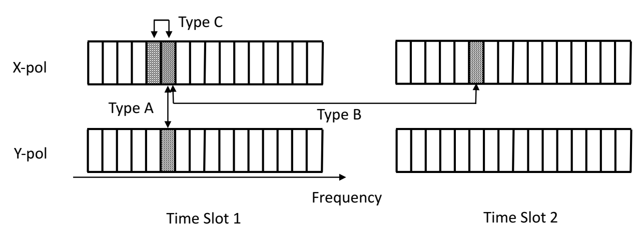

Fig. 1: Schematic of the three options of mapping 4D signals with complementary amplitude. Type A, B, and C use two polarizations, two time slots, and two neighboring frequencies, respectively

We use a coded modulation formats based on 2A8PSK for 6 bits / 4D symbol, called 6b4D-2A8PSK [4]. We used a ring ratio of 0.65, which is optimum for nonlinear transmission conditions. The 4D signals are typically mapped to X- and Y-polarization in one time slot [4] shown as Option A in Fig. 1. Alternatively, 4D signal can be mapped onto two time slots (Option B) [5], or two neighboring subcarriers (Option C) which is introduced in this paper. We also use DP-Star-8QAM as a comparison for 6b4D-2A8PSK, which has the same spectral efficiency. At a normalized GMI of 0.86 (total GMI = 3.44 b/s/Hz/4D), 6b4D-2A8PSK of all three mapping options has 0.23 dB smaller required signal to noise ratio (SNR) than DP-Star-8QAM under additive white Gaussian noise (AWGN).

Simulation procedures are similar to that reported in the previous work [4]. For the transmitter, all the subcarriers were combined, and no optical filter was used. The link comprised 50 spans of 80 km standard single mode fiber (SSMF) without inline dispersion compensation. SSMF parameters are, $\gamma = 1.2$ /W/km; $D = 17$ ps/nm/km; $\alpha = 0.2$ dB/km. No dispersion pre-compensation was used. In order to quantify performance over the link for multiple modulation formats, the span loss budget achieving the target GMI was used as a performance metric. Other fiber effects such as dispersion slope and polarization mode dispersion were not simulated. An ideal homodyne coherent receiver was used, with an RRC filter followed by sampling at twice the symbol rate. Following this, ideal chromatic dispersion equalization and data-aided least-mean-square equalization were employed. No laser linewidth was considered. All the optical noise due to the EDFA is loaded just before the receiver. We varied the optical signal-to-noise ratio (OSNR) such that the target GMI is reached. The obtained required OSNR is used to calculate the span loss budget, where EDFA noise figure of 5 dB is assumed. Nonlinearity compensation has not been applied.

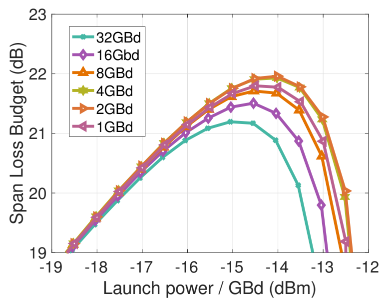

Fig. 2: Span loss budget for 6b4D-2A8PSK format Type C as a function of launch power per GBd.

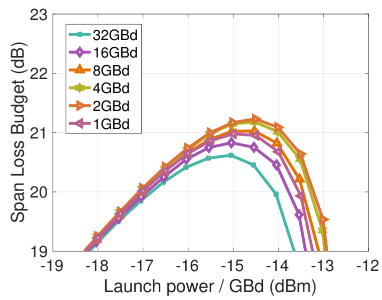

Fig. 3: Span loss budget for DP-Star-8QAM format as a function of launch power per GBd.

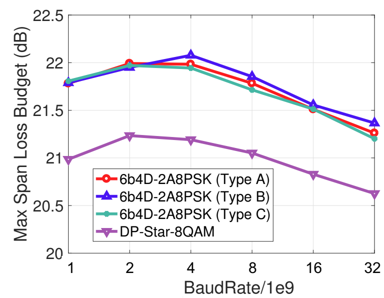

Fig. 4: Maximum span loss budget of the four modulation format as a function of baud rate.

Fig. 2 shows the calculated span loss budget for 6b4D-2A8PSK Type C as a function of the launch power per GBd (i.e., normalized by the bandwidth) with a target GMI of 0.86. The lowest peak span loss budget is when the subcarrier is modulated at 32 GBd. and it gradually increases as the baud rate decreases and the peak is when the baud rate is 2-4 GBd. Fig. 3 shows the span loss budget for DP-Star-8QAM with the same target GMI. By comparing Fig. 2 and Fig. 3 , we can conclude that the 4D constant modulus format is even more beneficial when the subcarrier baud rate is 2-4 GBd.

We also plotted the peak span loss budget of 6b4D-2A8PSK with three mapping options and DP-Star-8QAM as a function of the subcarrier baud rate as shown in Fig. 4. All three mapping resulted in 0.8-0.9 dB higher than DP-Star-8QAM. Among the three mapping options, the results are within 0.1 dB with each other. Type B showed slightly better results on average. The further study on the physical explanation is ongoing. These results indicate that mapping options does not affect the nonlinear performance significantly, and this gives flexibility in how the digital signal processor is configured.

3. Conclusion

We investigated three mapping options of 4D constant modulus formats as the constituent of the multi-subcarrier modulation through simulation over a dispersion uncompensated link. These three options gave very similar results. This will lead to flexibility in designing coherent transceivers.

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