LATENCY REDUCTION VIA BYPASSING SOFT-DECISION FEC OVER SUBMARINE SYSTEMS

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Abstract: In this paper, an 100Gb/s dual-carrier dual-polarization BPSK has been simulated to transmit over transoceanic uncompensated link with more than 3-dB hard-decision FEC limit, thus enabling the bypass of the soft-decision LDPC module to reduce the decoding latency by 20~30 micro seconds. Other than laying out a new route with shorter distance, this low-latency option makes submarine systems more flexible for the customers' request. Meanwhile, the impact of LDPC iterative decoding has been systematically simulated with respect to coding performance. In addition, the subcarrier spacing between the carriers has been investigated to increase the spectral efficiency whilst maintaining the low-latency feature.

1 INTRODUCTION

Undersea cable plays a critical role in upholding the timely communication between continents nowadays. The capacity of single fiber could go up to 30 Tb/s at trans-Atlantic distances with the sophisticated digital coherent technologies: such as advanced low-density parity check (LDPC) codes and Nyquist spectrum shaping [1]. However, the commercial and favourable modulation formats for trans-oceanic transmission would be dual-polarization (DP) binary phase-shifted-keying (BPSK), and DP quadrature phase-shifted-keying (QPSK), because of higher receiver sensitivity and better nonlinearity tolerance compared with higher-order (>4 level) quadrature amplitude modulation (QAM) [2]. DP-QPSK always stands out for uncompensated link while DP-BPSK is selected for upgrading over dispersion-managed fiber (DMF) link.

On the other hand, low latency over submarine fiber cables is also attracting more and more attention for speeding up the business exchange and teleconferencing over different continents. Of significance is that the recent deployment of trans-Arctic ocean submarine fiber cable between London and Tokyo could reduce the latency by 60 millisecond at the cost of 1.5 billion [3]. The new route spans about 16,000 km from these two cities; in contrast, it could take up to 24,000 km to send packages over the conventional link [3]. Obviously, the cost is huge to lay out this new route for reducing latency. Therefore, reducing the latency over submarine cables becomes very interesting topic!

In this paper, the dual-peak 32Gbaud DP-BPSK has been studied to replace the single-carrier 32Gbaud DP-QPSK over uncompensated link to reduce transmission latency within single submarine cable via avoiding LDPC encoding/decoding. The performance of DP-QPSK and DP-BPSK is comprehensively studied over the developed new type of large-core/low-loss fiber. Finally, the impact of LDPC design is briefly discussed for coding performance and latency reduction.

2 SIMULATION SETUP

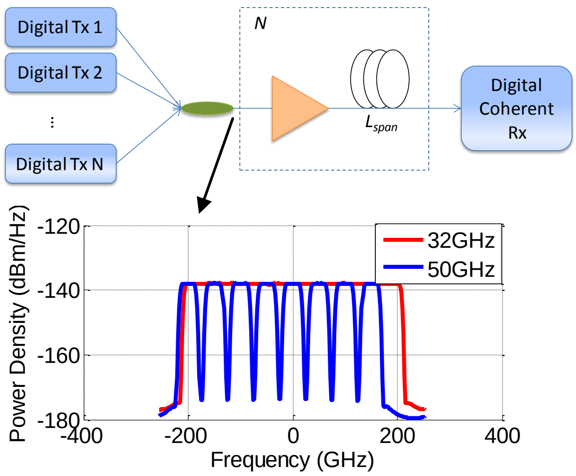

Figure 1 : Simulation schematic.

The simulation schematic (see Figure 1) consist of *N* digital transmitters capable of producing Nyquist-shaped 32Gbaud DP-QPSK and DP-BPSK signals spanning over 400 GHz bandwidth. The exact number of channels are 8, 11, 12, 13 and 13, respectively, for the channel spacing at 50GHz, 37.5 GHz, 35 GHz, 33 GHz, and 32 GHz. The inset of Fig. 1 displays the WDM spectrum at 50GHz and 32GHz channel spacing. Note that the superchannel transmitter configuration is assumed for 32GHz channel spacing to avoid laser drifting issues. Of importance is that the digital transmitter is used for tighter channel packing compared with optical Nyquist shaping technology. The presence of digital transmitter also provides flexibility to the transponder for kind of software-defined optics (SDO) features, such as agile modulation formats. The emulated 12,000km link is a new developed ultra low-loss (0.16 dB/km), large-core ($146\mu m^2$) fiber with average chromatic dispersion (CD) of 21 ps/nm/km at 1550 nm. The noise figure of EDFA is assumed to be 6 dB and additional 0.6 dB splicing loss is emulated per span. The standard digital signal processing (DSP) algorithm is applied at the receiver side to recover the signals.

3 SIMULATION RESULTS

Due to the very low bit error rate (BER) of BPSK, all the Q-factor for both modulation formats is estimated from the recovered signal constellation for consistency. The accuracy is sufficient for providing the measurement tool for evaluating the system performance at low BER regime where BER counting is difficult to be implemented.

3.1 Performance Comparison between 32Gbaud DP-BPSK and DP-QPSK

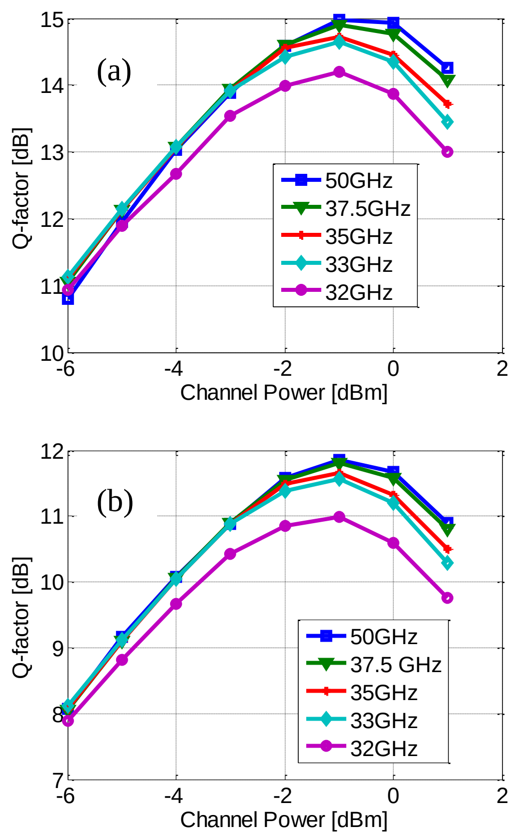

Figure 2: 12,000km transmission performance of (a) DP-BPSK and (b) DP-QPSK.

Figure 2 (a) and (b) plot the transmission performance of DP-QPSK and DP-BPSK over 12,000 km uncompensated link at 60 km span length. As observed, the Q-factor for DP-BPSK is more than 3 dB higher than its counterpart DP-QPSK due to half bit rate. The performance of DP-BPSK has better fiber nonlinearity than DP-QPSK, thus attributing to the additional 0.2 dB Q-

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factor improvement over DP-QPSK at the optimum channel power. The optimum launch power for both modulation formats is the same, -1 dBm per channel. The Q-factor of DP-BPSK after 12,000km could be as high as 15 dB, which is much higher than the hard-decision (HD) forward error correction (FEC) limit (BER=3.8×10^{-3}) [4]. In other words, at all the channel spacing scenario, the HD-FEC is sufficient for DP-BPSK over trans-pacific distance with more than 3 dB system margin while reducing the extra latency incurred by LDPC encoding/decoding.

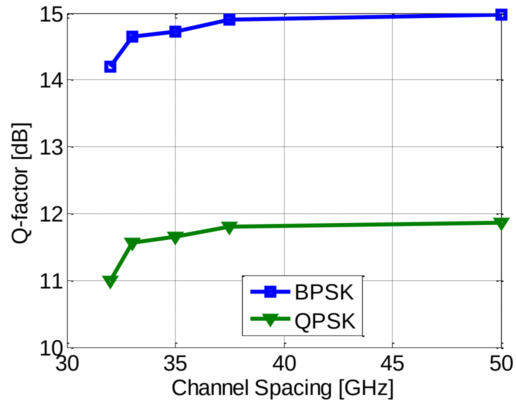

Figure 3: Impact of channel spacing on DP-QPSK and DP-BPSK.

As shown in Fig. 3, the penalty of packing both signals at 32 GHz spacing is less than 1 dB due to the well-confined Nyquist spectrum shaping in the digital transmitter.

3.2 Impact of Span Length

The other advantage of DP-BPSK is to increase the span length whilst maintaining sufficient system margin. As shown in Fig. 4, the performance of both signals has dropped about 3.6 dB at the linear regime from 90km span to 120 km span, accounting for the additional 4.8 dB span loss and less EDFAs (100) at 120km case. However, the optimum channel power also increases as span length keeps increasing.

In the simulation, the optimum launch power has shifted from -1 dBm for 60km span length to +1 dBm for 90km span and +2 dBm for 120 km span length. Of interest, the increment of optimum channel power approximately scales with the span length. The ultimate performance of DP-BPSK and DP-QPSK at 120km span length is about 2.4 dB worse than the one at 90 km span length. Fig. 5 plots the performance degradation as a function of span length. As for both signals, ~ 1.3 dB and ~2.4 dB penalty has been observed from 60 km span to 90km, and 120 km span length. Depending on the system margin, longer span could be deployed at the expense of extra system margin in the received signals. Note that the impact of span length over both DP-QPSK and DP-BPSK is quite similar. In general, 32Gbaud DP-BPSK could support up to ~107 km span length transmission at 32GHz channel spacing. In contrast, DP-QPSK cannot make this distance with 3dB HD-FEC margin at the same channel spacing!

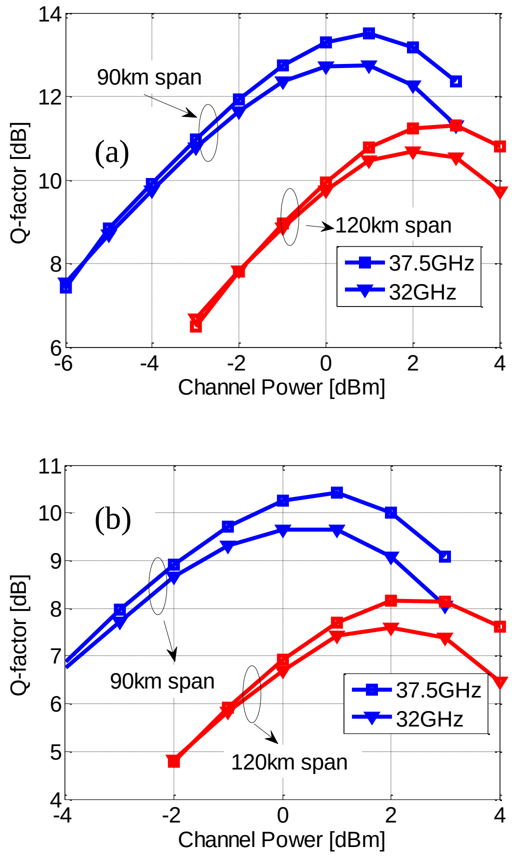

Figure 4: Transmission performance of (a) DP-BPSK and (b) DP-QPSK at 90km (in total

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11,700 km) and 120km (in total 12,000km) span length.

Figure 6 displays the Q-factor versus distance at 120 km span length. DP-BPSK could transmit over 9900km with >3 dB HD-FEC system margin while DP-QPSK can only go up to 4800 km.

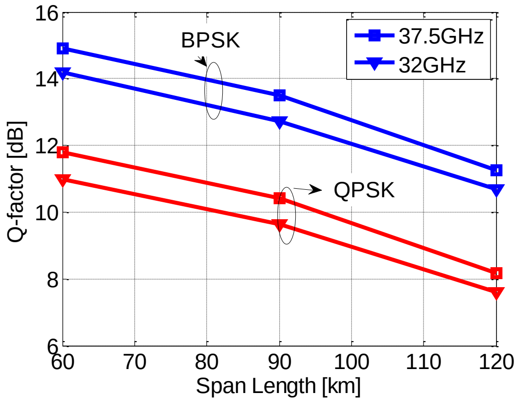

Figure 5: The optimum performance at each span length.

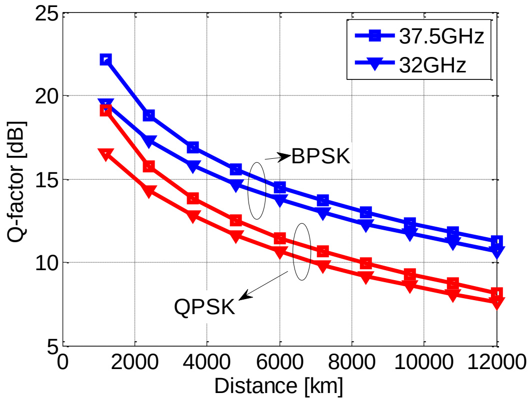

Figure 6: The simulated Q-factor versus distance.

4 DISCUSSION OF LDPC DESIGN

Longer LDPC codes of high rates, large girth and sufficient iterations of soft-iterative decoding are preferred in optical transmission because of large coding gain (CG) and high spectral efficiency [5]. However, such code is usually associated with higher complexity of variable node update rule and long latency. Therefore, it is highly desirable to see how these parameters affect the code performance and provide reference for the real applications.

We first evaluate a set of LDPC codes of girth (g) 10 and column weight (c.w.) 3 in terms of BER vs. signal-to-noise ratio performance. Typically, lower-rate (R) code has better performance at the cost of using more redundancy bits while longer block length (N) helps as more cycles in the Tanner graph are removed. As Figure 7 shows, lowering R from 0.8 to 0.75 with N=16935 CG is improved by ~0.4 dB at BER=10^{-7} while tripling N CG of the R=0.8 code is improved by 0.1 dB while the R=0.75 code benefits 0.1 dB more as more cycles are removed.

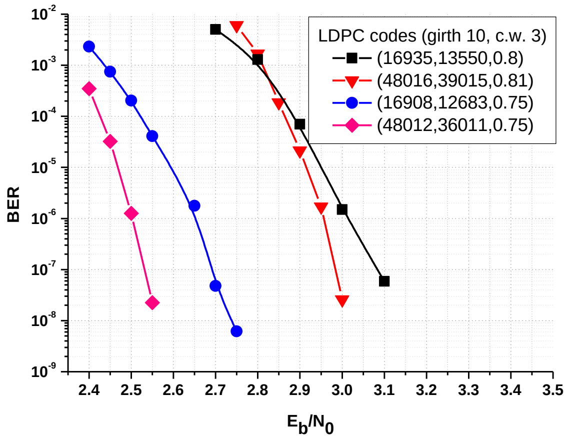

Figure 7 : Impact of code rate and block length on code performance

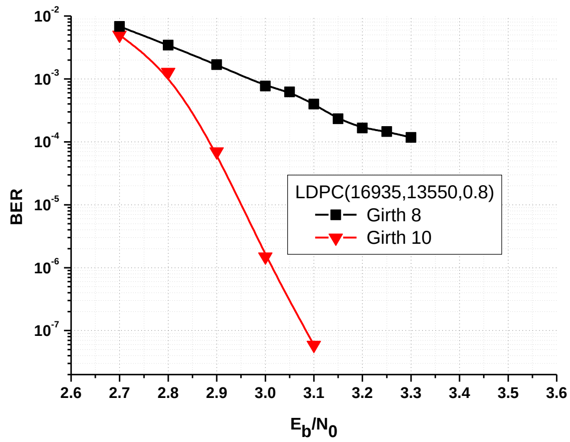

Figure 8: Impact of girth on code performance

We reveal the impact of girth with a pair of LDPC codes of g=8 and 10 with N=16935 and c.w. = 3 in Figure 8. We show that *g*=10 is necessary to lower or remove the error floor which agrees with the statement in [6].

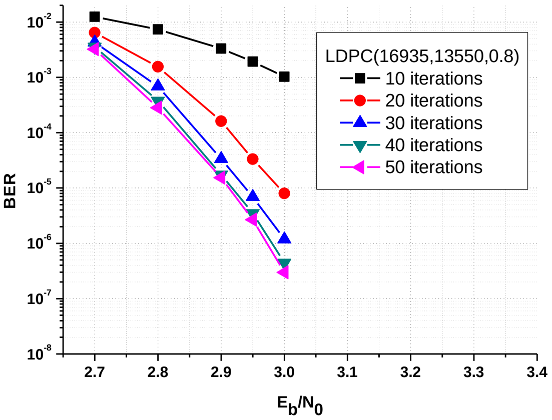

Figure 9: Impact of number of iteratation of iterative decoding

Figure 9 gives the effect of number of iterations in soft-iterative decoding with sum-product algorithm. For the code of *N*=16935, *g*=10, c.w.=3 and *R*=0.8, we see the performance converges as it goes up to 50 iterations and at least 20 iterations are needed for sufficient coding gain. It is worth to point out that only less than 0.1 dB gain could be achieved by increasing the iteration number from 20 to 40 and doubling the decoding latency indicating that a reasonable number of iterations for soft-iterative decoding should be adopted trading off between coding gain and decoding latency.

To sum up, the LDPC code should be optimally designed in terms of block length, girth and decoding iterations by balancing coding gain, latency and implementation complexity as well as power consumption.

5 CONCLUSION

In this paper, the comprehensive performance comparison between 32Gbaud DP-BPSK and DP-QPSK has been performed in the simulation over low-loss/large-core fiber link. Simulation shows that DP-BPSK could transmit over 9900km with >3 dB HD-FEC system margin while DP-QPSK can only go up to 4800 km at 120 km span length, thereby enabling the bypass of the soft-decision LDPC module to reduce the decoding latency by 20~30 micro seconds. The impact of span length on DP-BPSK suggests that longer span would suffer from less-than-expected performance degradation due to its higher launch power, which scales with the span length. Finally, the impact of block length, girth and iteration number has been simulated with respect to LDPC code performance.

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