TRANSMISSION CAPACITY ENHANCEMENT BY HIGHER BIT-RATE SIGNAL UPGRADES IN LEGACY CABLE SYSTEMS

Takehiro Nakano (1), Takanori Inoue (1), Fatih Yaman (2), Eduardo Mateo (1), Yoshihisa Inada (1) and Takaaki Ogata (1)

Email: < t-nakano@dr.jp.nec.com>

(1) Submarine Networks Division, NEC Corporation 34-6, Shiba 5-chome, Minato-Ku, Tokyo, 108-0014, Japan

(2) NEC Laboratories America , Princeton, NJ 08540, USA

Abstract: This paper analyses 40Gbps and 100Gbps signal upgrades for legacy cable systems. Upgradeability of 40Gbps waves for trans-Pacific systems has been experimentally verified by employing DP-BPSK modulation with 0.8bit/s/Hz spectral efficiency. For further capacity expansion, 100Gbps upgradeability is also discussed and advanced technologies, such as spectral shaping and non-linearity compensation, are introduced.

1 INTRODUCTION

Significant efforts have been made towards the capacity expansion of existing submarine cable systems using 40Gbps and higher rate signal. Thanks to the progress in DSP-based digital coherent technology, 40Gbps and even 100Gbps systems based on multi-level modulation and polarization multiplexing have become commercially available, enabling much higher capacity than the previous systems based on non-coherent modulation formats. However, the applicable distance range for 40Gbps and 100Gbps is still limited by the effects of ASE noise accumulation and fiber non-linearity. One of the fundamental limitations comes from the fact that legacy cable systems are optimized for non-coherent modulation formats which require in-line dispersion compensation links based on Non-Zero Dispersion Sifted Fiber (NZ-DSF) or Dispersion Managed Fiber (DMF).

This paper presents our capacity expansion results using 40Gbps and 100Gbps signals for legacy cable systems together with the key technologies involved.

2 40G UPGRADES FOR LEGACY CABLE SYSTEM

2.1 DP-QPSK Transmission Performance

Dual-Polarization Quadrature-Phase-Shift-Keying (DP-QPSK) modulation is one of promising candidates for 40Gbps capacity upgrading thanks to its high receiver sensitivity, high spectral efficiency, tolerance to polarization mode dispersion and tolerance to linear spectral filtering. We have investigated the transmission performance of 40Gbps DP-QPSK signal experimentally in two types of transmission lines. One is the NZ-DSF-based transmission line, and the other is the DMF based line. Figure 1 shows the 40Gbps DP-QPSK transmission performances for the NZ-DSF line and the DMF line as a function of transmission distance. The 40Gbps DP-QPSK signals were allocated with 50GHz spacing. By assuming a 25 years system margin of around 3dB over the FEC detection limit, allowable transmission distance for

40Gbps DP-QPSK signal is approximately 5,000 km for NZ-DSF line and 7,000 km for DMF line.

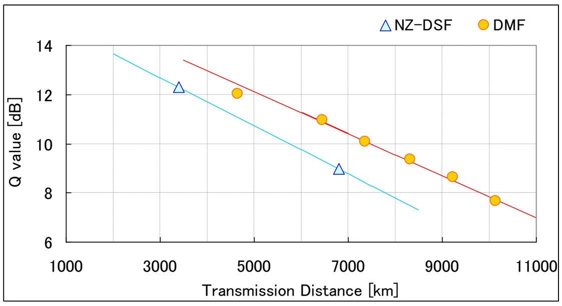


Figure 1: Transmission Performance of 40Gbps DP-QPSK

2.2 DP-BPSK Transmission performance

To expand the maximum reach beyond the above limitations, we have analyzed Dual-Polarization Binary-Phase-Shift-Keying (DP-BPSK) modulation format, which has increased non-linear tolerance due to its intrinsic robustness against phase noise. In this evaluation, we have employed a 40Gbps DP-BPSK signal composed of two 25GHz spaced subcarriers modulated with 10Gbaud DP-BPSK symbols as shown in Figure 2. Figure 3 shows a comparison of the channel power dependency of 40Gbps DP-QPSK and DP-BPSK after 6,800 km transmission over a NZ-DSF line. It is clear from Fig. 3 that DP-BPSK modulation provides a significant advantage in terms of nonlinearity tolerance. This is confirmed by a Q value increase of more than 2.5dB compared to the DP-QPSK signal.

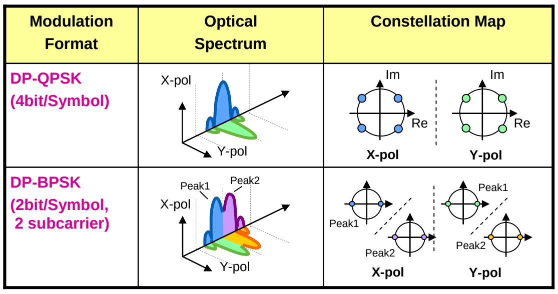


Figure 2: DP-QPSK and DP-BPSK

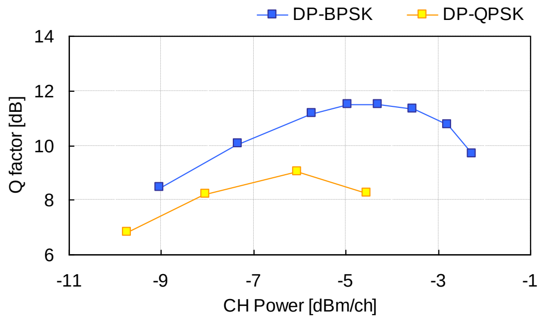
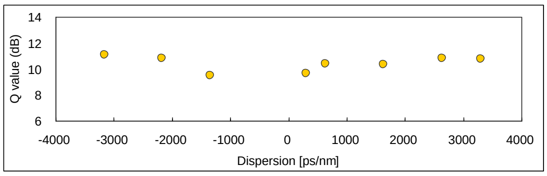


Figure 3: Channel Power Dependency of 40Gbps DP-BPSK after 6,800 km NZ-DSF Transmission

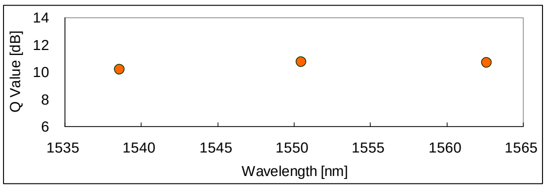
2.3 Transmission Performance of 40Gbps DP-BPSK Signal over Trans-Pacific Distance

To confirm the capacity upgradeability using 40Gbps DP-BPSK signals over trans-Pacific legacy cable, we have evaluated the transmission performance of 40Gbps DP-BPSK signal over 9,000 km for a NZ-DSF line and a DMF line. Both dispersion maps are tightly managed and optimized for 10Gbps RZ-OOK signal transmission.

Figure 4(a) shows the transmission performance of 40Gbps DP-BPSK over 9,000 km transmission for the NZ-DSF fiber. 40Gbps DP-BPSK signal shows a Q value exceeding 10dB except for wavelengths located near the zero-dispersion where the nonlinear cross-phase modulation degradation is the largest. Figure 4(b) shows the transmission results over 9,000 km of DMF fiber. Thanks to the flattened dispersion characteristics, Q values show now an equalized behaviour among all the wavelengths with more than 10dB. According to these transmission performance assessments, the feasibility of 40Gbps capacity upgrades is confirmed for trans-pacific cable systems by taking advantage of the superior non-linearity tolerance of DP-BPSK modulation.



(a) NZ-DSF line



(b) DMF line

Figure 4: Transmission Performance of 40Gbps DP-BPSK over 9,000 km

3 100G UPGRADES FOR LEGACY CABLE SYSTEM

Capacity expansion using 100Gbps wavelengths is becoming of utmost important in order to provide a seamless inter-connection with the rapidly growing terrestrial 100Gbps systems. However, 100Gbps signal has an inherent 4dB receiver sensitivity penalty with respect to 40Gbps as a result of the baud rate increase. Figure 5 shows the performance comparison of 40Gbps DP-QPSK signal and 100Gbps DP-QPSK signal over 7,000 km transmission of DMF Fiber. As shown in this figure, the transmission distance of 100G is now limited to 4,000 km due to the above mentioned OSNR penalty.

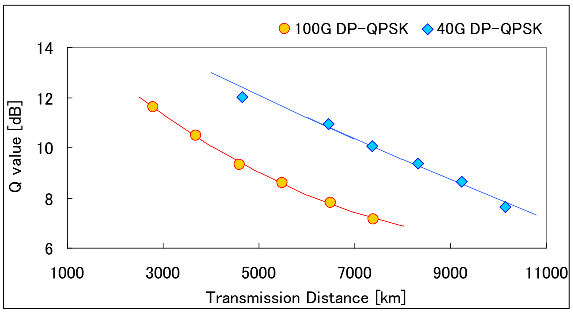


Figure 5: Transmission Performance of 40Gbps DP-QPSK and 100G DP-QPSK

To increase the 100G transmission reach over legacy cable systems, the deployment of new technologies are indispensable, even beyond the choice of the most nonlinearity tolerant modulation format, such as DP-BPSK modulation, and superior FEC technology [1]. Towards 100G capacity upgrades for trans-Pacific distance transmission system, we have extensively studied advanced technologies such as signal spectral shaping and non-linear compensation and their effectiveness has been verified through long distance transmission experiment.

3.1 Spectral Pre-Shaping for increased nonlinearity tolerance

One of the technologies for nonlinearity mitigation is spectral pre-shaping. Figure 6 shows the optical spectra of 100Gbps DP-QPSK WDM signals with and without spectral pre-shaping. Techniques based on spectral flattening contribute both to the mitigation of inter-channel interference and to the mitigation of fiber non-linearity thanks to the lower spectral peak level. Figure 7 shows the experimental improvement factor by spectral pre-shaping for 100Gbps DP-QPSK signal after 10,000 km transmission of SMF line. Spectral pre-shaping technique effectively enhances the transmission performance by reducing the nonlinearity-induced power penalty as much as by 1 dB in the higher non-linear region.

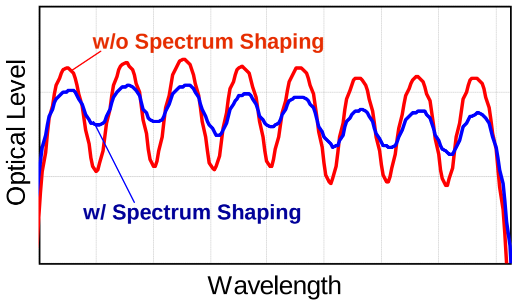


Figure 6: Spectrum of 100Gbps DP-QPSK Signal with Spectrum Shaping

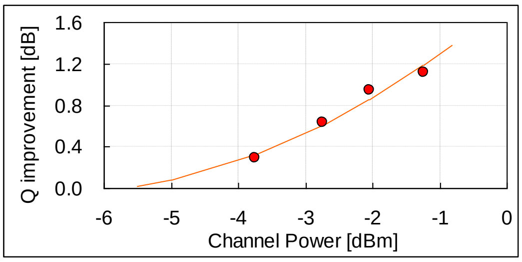


Figure 7: Channel Power Dependency of Q Improvement of 100Gbps DP-QPSK after 10,000 km SMF Transmission

3.2 Nonlinear Compensation

Nonlinearity compensation based on digital back-propagation (DBP) is also a promising approach to enhance the transmission performance. Typically, DBP is performed using the well-known split-step method. By back-propagating the received signal digitally through a virtual fiber with inverted parameters waveform distortion experienced during physical transmission can be compensated as shown in Figure 8.

In order to reduce the intrinsic multi-step complexity of DBP, we have proposed a simplified back-propagation based on the concept of equivalent link [2]. Figure 9 shows the experimental results of 100Gbps DP-QPSK transmission by using our proposed simplified DBP. In this evaluation, 50GHz spaced 100Gbps DP-QPSK signals are transmitted over a line consisting of a 3,400 km straight line with the NZ-DSF fiber. By applying a simplified DBP based on the equivalent link approach, the optimum channel power is increased and Q performance is also improved by almost 1dB.

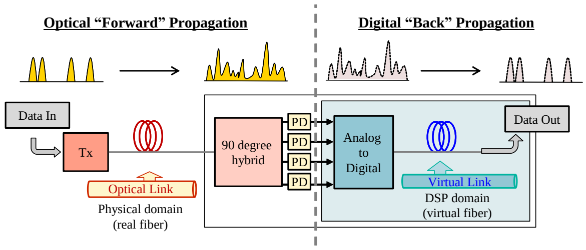


Figure 8: Back-Propagation Method

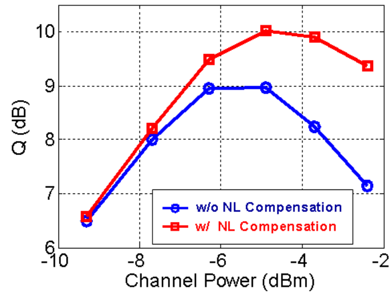


Figure 9: Channel Power Dependency of 100Gbps DP-QPSK after 3,400 km NZ-DSF Transmission

4 CONCLUSION

We have introduced our recent studies of 40Gbps and 100Gbps signal upgrading for the legacy submarine cable systems. 40Gbps upgradeability over trans-Pacific distance has been confirmed by applying the highly nonlinearity tolerant DP-BPSK modulation format. Towards further capacity expansion using 100Gbps signals, advanced technologies such as spectral pre-shaping and nonlinearity compensation are proposed and evaluated.

5 REFERENCES

[1] S. Zhang, et al., "Experimental Demonstration of Non-Binary LDPC Coded Modulation for Ultra-Long-Haul Transmission Systems", OFC2011, Tu.3.B.5

[2] T. Inoue, et al., "Low Complexity Nonlinearity Compensation for 100G DP-QPSK Transmission over Legacy NZ-DSF Link with OOK channels", ECOC2012, Mo.1.C.5