Intra-channel nonlinearity compensation for PM-16QAM traffic co-propagating with 28Gbaud *m*-ary QAM neighbours

Danish Rafique,[1,2,*] Stylianos Sygletos,[1] and Andrew D. Ellis[1,3]

[1]*Photonic Systems Group, Tyndall National Institute, University College Cork, Ireland*
[2]*Now with Nokia Siemens Networks, S.A., Lisbon, Portugal*
[3]*Now with Aston Institute of Photonic Technologies, University of Aston, UK*
[*]*danish.rafique.ext@nsn.com*

Abstract: We quantify the benefits of intra-channel nonlinear compensation in meshed optical networks, in view of network configuration, fibre design aspect, and dispersion management. We report that for a WDM optical transport network employing flexible 28Gbaud PM-mQAM transponders with no in-line dispersion compensation, intra-channel nonlinear compensation, for PM-16QAM through traffic, offers significant improvements of up to 4dB in nonlinear tolerance (Q-factor) irrespective of the co-propagating modulation format, and that this benefit is further enhanced (1.5dB) by increasing local link dispersion. For dispersion managed links, we further report that advantages of intra-channel nonlinear compensation increase with in-line dispersion compensation ratio, with 1.5dB improvements after 95% in-line dispersion compensation, compared to uncompensated transmission.

OCIS codes: (060.1660) Coherent communications; (060.4254) Networks, combinatorial network design; (060.4370) Nonlinear optics, fibers.

References and links

1. A. D. Ellis, J. Zhao, and D. Cotter, "Approaching the Non-Linear Shannon Limit," J. Lightwave Technol. **28**(4), 423–433 (2010).
2. P. J. Winzer, A. H. Gnauck, C. R. Doerr, M. Magarini, and L. L. Buhl, "Spectrally Efficient Long-Haul Optical Networking Using 112-Gb/s Polarization-Multiplexed 16-QAM," J. Lightwave Technol. **28**(4), 547–556 (2010).
3. M. Suzuki, I. Morita, N. Edagawa, S. Yamamoto, H. Taga, and S. Akiba, "Reduction of Gordon-Haus timing jitter by periodic dispersion compensation in soliton transmission," Electron. Lett. **31**(23), 2027–2029 (1995).
4. C. Fürst, C. Scheerer, and G. Mohs, J. -. Elbers, and C. Glingener, "Influence of the dispersion map on limitations due to cross-phase modulation in WDM multispan transmission systems," Optical Fiber Communication Conference, OFC '01, MF4 (2001).
5. A. Carena, V. Curri, P. Poggiolini, and F. Forghieri, "Optical vs. Electronic Chromatic Dispersion Compensation in WDM Coherent PM-QPSK Systems at 111 Gbit/s," Optical Fiber Communication Conference, OFC '08, JThA57 (2008).
6. X. Li, X. Chen, G. Goldfarb, E. Mateo, I. Kim, F. Yaman, and G. Li, "Electronic post-compensation of WDM transmission impairments using coherent detection and digital signal processing," Opt. Express **16**(2), 880–888 (2008).
7. D. Rafique, J. Zhao, and A. D. Ellis, "Digital back-propagation for spectrally efficient WDM 112 Gbit/s PM m-ary QAM transmission," Opt. Express **19**(6), 5219–5224 (2011).
8. S. J. Savory, G. Gavioli, E. Torrengo, and P. Poggiolini, "Impact of Interchannel Nonlinearities on a Split-Step Intrachannel Nonlinear Equalizer," IEEE Photon. Technol. Lett. **22**(10), 673–675 (2010).
9. X. Zhou, E. F. Mateo, and G. Li, "Fiber Nonlinearity Management-from Carrier Perspective," Optical Fiber Communication Conference, OFC '11, NThB4 (2011).
10. A. Nag, M. Tornatore, and B. Mukherjee, "Optical Network Design With Mixed Line Rates and Multiple Modulation Formats," J. Lightwave Technol. **28**(4), 466–475 (2010).
11. C. Meusburger, D. A. Schupke, and A. Lord, "Optimizing the Migration of Channels with Higher Bitrates," J. Lightwave Technol. **28**(4), 608–615 (2010).
12. D. Rafique and A. D. Ellis, "Nonlinear Penalties in Dynamic Optical Networks Employing Autonomous Transponders," IEEE Photon. Technol. Lett. **23**(17), 1213–1215 (2011).

#174909 - $15.00 USD Received 4 Sep 2012; revised 30 Oct 2012; accepted 30 Oct 2012; published 11 Feb 2013

13. T. Wuth, M. W. Chbat, and V. F. Kamalov, "Multi-rate (100G/40G/10G) Transport Over Deployed Optical Networks," Optical Fiber Communication Conference, OFC'08, NTuB3, (2008).
14. D.v.d Borne, C.R.S. Fludger, T. Duthel, T. Wuth, E.D. Schmidt, C. Schulien, E. Gottwald,G.D. Khoe, and H. de Waardt, "Carrier phase estimation for coherent equalization of 43-Gb/s POLMUX-NRZDQPSK transmission with 10.7-Gb/s NRZ neughbours," ECOC'07, 7.2.3 (2007).
15. C. Fürst, J. Elbers, H. Wernz, H. Griesser, S. Herbst, M. Camera, F. Cavaliere, A. Ehrhardt, D. Breuer, D. Fritzsche, S. Vorbeck, M. Schneiders, W. Weiershausen, R. Leppla, J. Wendler, M. Schroedel, T. Wuth, C. Fludger, T. Duthel, B. Milivojevic, and C. Schulien, "Analysis of Crosstalk in Mixed 43 Gb/s RZ-DQPSK and 10.7 Gb/s DWDM Systems at 50 GHz Channel Spacing," Optical Fiber Communication Conference, OFC'07, OThS2 (2007).
16. R.-J. Essiambre, G. Raybon, and B. Mikkelsen, *Optical Fiber Telecommunications IV* (Academic, 2002), chap.6.
17. C. S. Fludger, T. Duthel, D. van den Borne, C. Schulien, E.-D. Schmidt, T. Wuth, J. Geyer, E. De Man, Khoe Giok-Djan, and H. de Waardt, "Coherent Equalization and POLMUX-RZ-DQPSK for Robust 100-GE Transmission," J. Lightwave Technol. **26**(1), 64–72 (2008).
18. D. Rafique and A. D. Ellis, "Nonlinear penalties in long-haul optical networks employing dynamic transponders," Opt. Express **19**(10), 9044–9049 (2011).
19. D. Rafique and A. D. Ellis, "Nonlinear and ROADM induced penalties in 28 Gbaud dynamic optical mesh networks employing electronic signal processing," Opt. Express **19**(18), 16739–16748 (2011).
20. J. Tang, "The multispan effects of Kerr nonlinearity and amplifier noises on Shannon channel capacity of a dispersion-free nonlinear optical fiber," J. Lightwave Technol. **19**(8), 1110–1115 (2001).
21. K. Mukasa, K. Imamura, I. Shimotakahara, T. Yagi, and K. Kokura, "Dispersion compensating fiber used as a transmission fiber: inverse/reverse dispersion fiber," OFC **3**(5), 292–339 (2006).
22. D. Rafique, M. Mussolin, M. Forzati, J. Mårtensson, M. N. Chugtai, and A. D. Ellis, "Compensation of intra-channel nonlinear fibre impairments using simplified digital back-propagation algorithm," Opt. Express **19**(10), 9453–9460 (2011).
23. L. Li, Z. Tao, L. Dou, W. Yan, S. Oda, T. Tanimura, T. Hoshida, and J. C. Rasmussen, "Implementation Efficient Nonlinear Equalizer Based on Correlated Digital Backpropagation," Optical Fiber Communication Conference, OFC '11, OWW3 (2011).
24. L. Zhu and G. Li, "Nonlinearity compensation using dispersion-folded digital backward propagation," Opt. Express **20**(13), 14362–14370 (2012).
25. D. Rafique and A. D. Ellis, "Various Nonlinearity Mitigation Techniques Employing Optical and Electronic Approaches," IEEE Photon. Technol. Lett. **23**(23), 1838–1840 (2011).
26. T. Tanimura, S. Oda, T. Hoshida, L. Li, Z. Tao, and J. C. Rasmussen, "Experimental Characterization of Nonlinearity Mitigation by Digital Back Propagation and Nonlinear Polarization Crosstalk Canceller under High PMD condition," Optical Fiber Communication Conference, OFC'11, JWA020 (2011).
27. L. B. Du and A. J. Lowery, "Experimental Demonstration of XPM Compensation for CO-OFDM Systems with Periodic Dispersion Maps," Optical Fiber Communication Conference, OFC'11, OWW2 (2011).

1. Introduction

Higher-order modulation formats are now used to improve spectral efficiency, but generally their tolerance towards channel impairments decreases [1,2]. Traditionally, various methods of compensating fibre transmission impairments have been proposed, both in optical and electronic domain. Dispersion management was initially proposed to suppress the impact of fibre nonlinearity with minimal residual dispersion at the receiver-side [3,4], leading to strongly dispersion-managed links deployed across the commercial networks today [4]. With the advent of coherent systems, digital signal processing (DSP) has enabled electronic domain impairment compensation removing the need for low residual dispersion [5], electronic filtering allowing for significantly reduced guard bands between channels, and improved OSNR tolerance. All of these aspects have altered the nonlinear dynamics of the link.

In particular, electronic signal processing employing linear and nonlinear compensation using digital back-propagation (DBP) has been proposed [6,7]. Typically, wide bandwidth DBP (inter-channel nonlinear compensation) is considered to be impractical, partly due to high computational load and partly due to limited access to all wavelength division multiplexed (WDM) channels [7]. Single-channel DBP (SC-DBP, intra-channel nonlinear compensation) has been shown to only enable modest improvements between ~1-2dB, compared to linear compensation only [7–9]. However, this has only been verified for systems employing homogenous network traffic, where all the channels carry same power [8]. As the network upgrades are carried out, it is likely that channels employing different multi-level formats will become operational, and the network traffic will become inhomogeneous

#174909 - $15.00 USD Received 4 Sep 2012; revised 30 Oct 2012; accepted 30 Oct 2012; published 11 Feb 2013

[10–12]. The impact of network planning strategies and cross-channel interaction involving on-off keyed neighbours has been quantified in [13–15], confirming the value of channel power allocation schemes in upgrading current networks [12,13].

It has been suggested that for green field deployments, DSP based impairment compensation would enable reductions in operational cost through the suppression of dual-stage amplifiers (only one amplifier would suffice) and dispersion compensation modules. However, as networks evolve it is inevitable that high-speed channels will also traverse through the existing dispersion-managed infrastructure. A vital aspect, from system design viewpoint, is then to determine the benefits available with DSP in already existing maps, and if dispersion management has any role to play in future network deployments.

Another approach to improve nonlinear tolerance is the use of fibres with higher local dispersion coefficients. It is well-understood that such a choice decreases the dispersion length, leading to reduced inter-channel nonlinearities, however at the expense of increased intra-channel nonlinear effects [16]. This leads to questions, regarding the optimum local link dispersion, the impact of dispersion management in controlling this optimum and the impact of intra channel nonlinearity compensation on link design.

In this paper we focus on quantifying the benefits available from intra-channel nonlinear compensation, considering aforementioned forward-looking questions, in view of network configuration and dispersion management, employing 28Gbaud PM-mQAM transponders. In Section 3.1 we consider the impact of the *network configuration*, and demonstrate that for networks with multi-level co-propagating traffic and no in-line dispersion compensation, with launched power fixed at the near-optimal for heterogeneous transmission [12], the benefit of intra-channel nonlinear compensation is increased from 1.5 dB (equal launch powers) to 4dB improvement in nonlinear tolerance for the highest bit-rate channels. In Section 3.2 we consider the *fibre design*, demonstrating that, as with linearly compensated systems, increasing the local link dispersion improves the performance with single-channel DBP. However, since the increased intra-channel effects are compensated by single-channel DBP, the rate of improvement is greater such that 5.5dB relative improvements are available if single-channel DBP is deployed instead of linear compensation for ultra-high dispersion fibres. Finally in Section 3.3, we extend this study to systems including in-line dispersion compensation. Our results are consistent with earlier results which show that with strong dispersion management, dispersion pre-compensation enables improved performance; however greater improvements are enabled by intra-channel nonlinear compensation for strongly dispersion managed links, compared to uncompensated maps.

2. Transmission model

Figure 1 illustrates the simulation setup. The transmission system comprised fifteen WDM channels employing 28Gbaud polarisation multiplexed quadrature amplitude modulation (PM-mQAM), m = 4, 16, 64, spaced at 50GHz. The central channel was always 28Gbaud PM-16QAM (at 1550nm), and the neighbours were selected to be PM-mQAM channels. For all the carriers both the polarisation states were independently modulated using de-correlated 2^{15} and 2^{16} pseudo-random bit sequences (PRBS), for x- and y- polarisation states, respectively. The optical transmitters consisted of continuous wave lasers (5kHz line-width) followed by two nested Mach-Zehnder Modulator structures for x- and y polarisation states, and the two polarization states were combined using an ideal polarization beam combiner. The simulation conditions ensured 16 samples per symbol, and 2^{13} symbols per polarization per channel.

The 28Gbaud PM-mQAM signals were propagated over diverse link configurations with 80km spans, residual dispersion per span varying from 0% (no in-line dispersion compensation) to 95% (95% in-line dispersion compensation), and erbium doped fibre amplifiers. The fibre had attenuation of 0.2dB/km, nonlinearity coefficient of 1.5/W/km, and dispersion coefficient of 20ps/nm/km (unless specified otherwise). We assumed ideal (linear

#174909 - $15.00 USD Received 4 Sep 2012; revised 30 Oct 2012; accepted 30 Oct 2012; published 11 Feb 2013

and lossless) dispersion compensating fibres (DCF), a condition which is approximately obtained in practical systems through the use of dual-stage amplifiers. Each amplifier stage was modeled by assuming a 4.5dB noise figure and 16dB gain. After fibre transmission, the central PM-16QAM signal was pre-amplified, filtered with a 35GHz 3rd order Gaussian de-multiplexing filter, coherently-detected using four balanced detectors to give the baseband electrical signal and sampled at 2 samples per symbol, followed by digital field reconstruction from the in-phase and quadrature samples. Transmission impairments were digitally compensated in two scenarios. Firstly, by using linear compensation (LC) alone (the back-propagation section in Fig. 1 was by-passed), employing finite impulse response filters adapted using a least mean square algorithm. In the second case, electronic compensation was applied via single-channel DBP (SC-DBP), which was numerically implemented by up-sampling the received signal to 16samples per symbol and reconstructing the optical field from the in-phase and quadrature samples, followed by split-step Fourier method based solution of nonlinear Schrödinger equation. The upper bound on the step-size was set to be 1 km and the step length was chosen adaptively during the integration along the fibre based on the condition that in each step the nonlinear effects must change the phase of the optical field by no more than 0.05 degrees. Polarisation de-multiplexing and residual dispersion compensation was then performed using a standard butterfly structure, followed by carrier phase recovery [17]. Finally, the symbol decisions were made, and the performance assessed by direct error counting (converted into Q-factor, Q^2 in dB). All the numerical simulations were carried out in VPItransmissionMaker®v8.6, and the DSP was performed in MATLAB®v7.10.

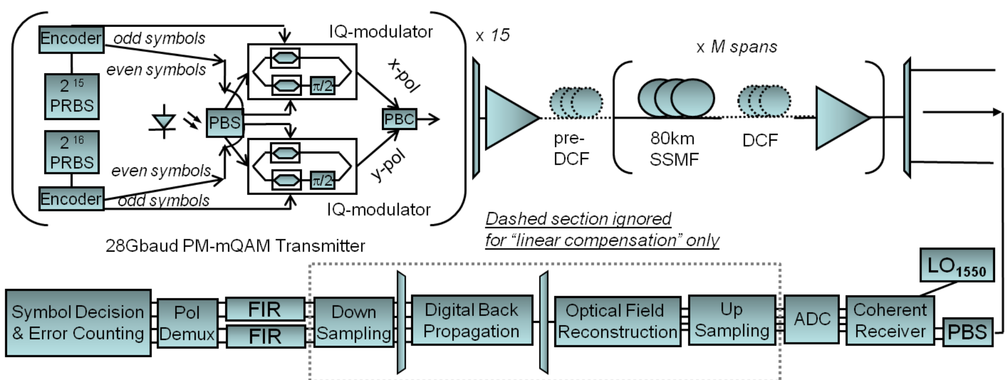

Fig. 1. Simulation setup for 28Gbaud PM-mQAM. PRBS: Pseudo random bit sequence, IQ: In-phase/Quadrature, DCF: dispersion compensating fibre, LO: local oscillator, PBC/S: polarisation beam combiner/splitter, ADC: analogue-to-digital converter, FIR: finite impulse response

3. Results and discussions

3.1 Impact of network configurations

In this section, we explore various network configurations, and report the benefits of intra-channel nonlinear compensation in such scenarios. Typical results of our simulations are shown in Fig. 2(a) as a function of signal launch power (P_L) for the central PM-16QAM channel, after 3,200km transmission. Specifically, we show four heterogeneous transmission scenarios: Circles, Squares and Stars, PM-4QAM/PM-16QAM/PM-64QAM neighbours respectively with 0dBm launch power for interfering channels, Diamonds, PM-4QAM neighbours with 4dBm launch power, and a fully homogenous scenario with all PM-16-QAM channels. Note that channel power allocation in a meshed network is an important system design choice [13], and in this work, the launch power of all the PM-mQAM neighbours was fixed at the near-optimal power of 0dBm for heterogeneous transmission, as shown in [12] (unless specified otherwise).

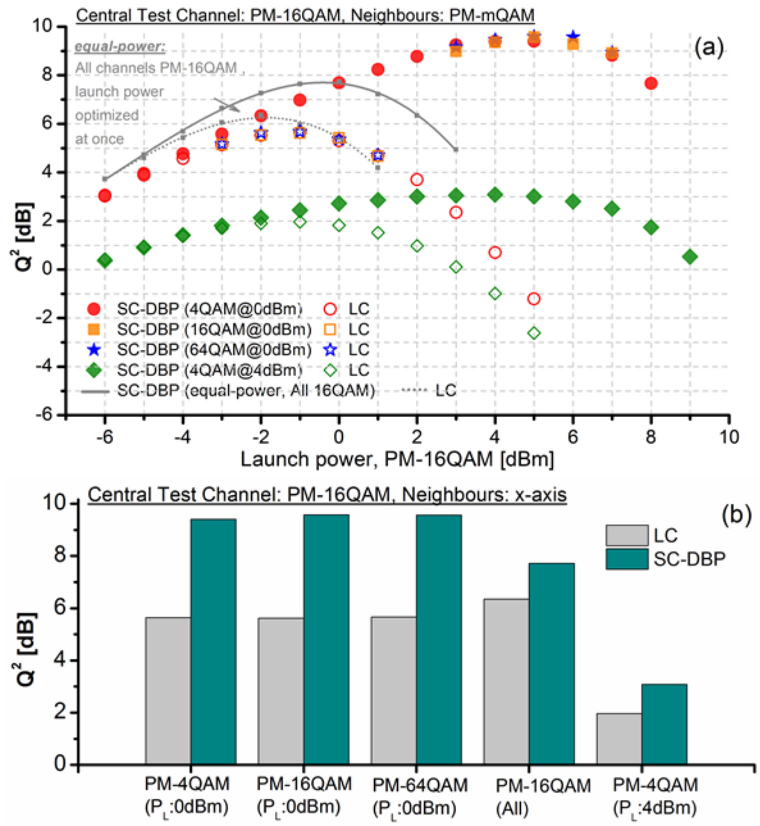

Fig. 2. (a) Q^2 of central PM-16QAM channel vs. launch power of PM-16QAM channel after 3,200km. Circles, Squares, Stars: PM-4QAM/PM-16QAM/PM-64QAM neighbours at 0dBm, Diamonds: PM-4QAM neighbours at 4dBm, Lines: curve fits PM-16QAM neighbours with launch power optimized with test-channel. Solid symbols and solid line: SC-DBP, Open symbols and dashed line: LC, (b) Q^2 with LC/SC-DBP, for various cases in (a).

The homogenous scenario, with equal-power PM-16QAM neighbours (varying launch power for all channels at once) demonstrates a Q-factor improvement of ~1.5dB when SC-DBP is enabled, consistent with previous works [7–9]. However, with lower-power PM-4QAM neighbouring traffic (most likely initial network scenario), SC-DBP increases the improvement in Q-factor to 4dB. Similar improvements are observed with PM-16QAM/PM-64QAM neighbours, representing network traffic of shorter reach. The performance improvements enabled here may be attributed to reduced cross-channel effects due to lower-power neighbouring traffic, however as it can be seen, the performance of the test channel appears independent of the neighbouring constellation size, modulated both in intensity and phase. We believe that this is because at 28Gbaud the peak-to-average power ratios become similar within a single span, for all QAM orders. Here, it is worth mention that the achievable performance gain would depend upon the distance covered by the neighbouring higher-order formats, where such design rules have been presented in [18]. If the launch power of neighbouring traffic is intentionally degraded, the cross-channel effects are exacerbated. In this case the improvement in Q-factor is reduced to the conventional 1 to 1.5dB range which remains a valuable improvement. The available Q-factor improvements achieved by enabling SC-DBP are summarised for clarity in Fig. 2(b). These results show that if each channel is only allocated sufficient power for its capacity needs, remaining channels will not only suffer lower inter-channel nonlinearity, but will also obtain increased benefit from SC-DBP, potentially allowing for operation at a higher bit-rates. Note that the achievable performance improvements, between 1.5dB and 4dB, also depend on the channel upgrade scenario, where the highest performance would be enabled for initial network upgrade [18]. Further details, from network operability view-point, may be found in [12,19], which clearly show the performance benefits available with this power allocation strategy [12], and that lower-order traffic may increase their modulation order, given SC-DBP is employed [19].

3.2 Impact of fibre design parameter

Having established the available benefits from SC-DBP in a flexible network, in this section, we explore the impact of fibre dispersion when higher power high bit-rate signals (PM-16QAM at its optimal launch power) co-propagate with lower power neighbours (PM-4QAM channels at 0dBm).

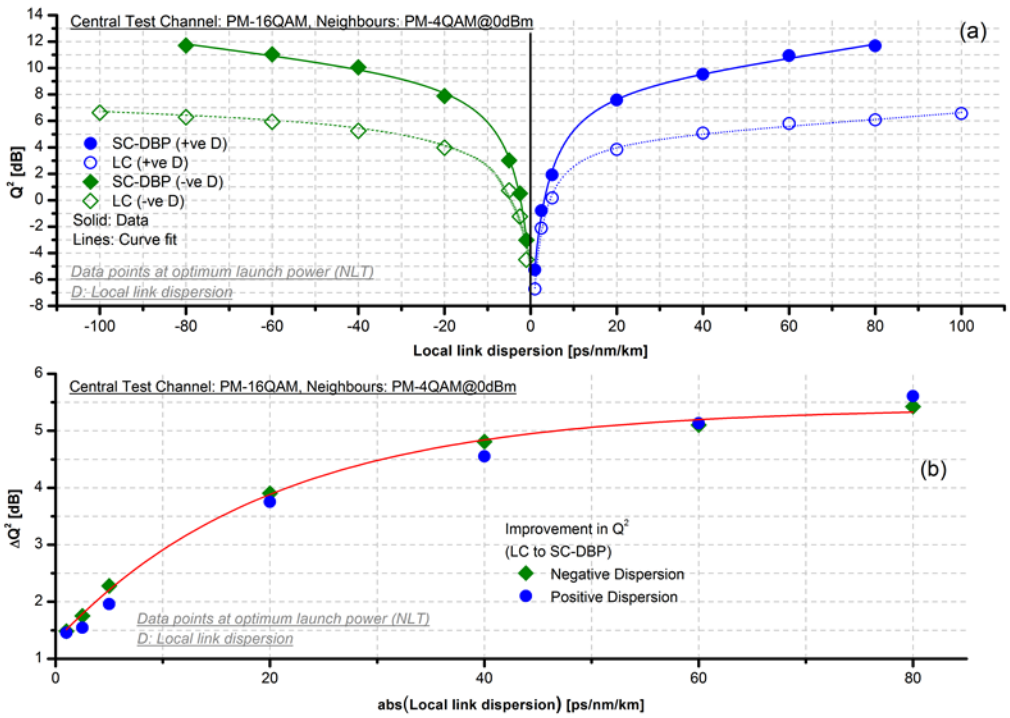

Fig. 3. (a) Q^2 of PM-16QAM channel (with PM-4QAM neighbours at 0dBm) versus local link dispersion after 4,800 km transmission. Circles: Positive dispersion coefficient, Diamonds: Negative dispersion coefficient. Solid symbols: SC-DBP, Open symbols: LC, Lines: guide. (b) Relative improvement from LC to SC-DBP for ± dispersion in (a).

Figure 3(a) plots the optimum performance of PM-16QAM test-channel as a function of local link dispersion coefficient after 4,800km transmission, both after LC (light symbols) and SC-DBP (dark symbols). It can be seen that increasing the absolute magnitude of the local dispersion enables improvements in system performance, with even greater improvements after SC-DBP. Increasing the dispersion, from a low value, results in aggressive performance improvements, due to reduced phase-matching effects [20] with little difference between LC and SC-DBP due to the dominance of inter-channel nonlinearities. As the local dispersion is increased further, the rate of improvement margin reduces due to the trade-off between inter-channel nonlinearities and intra-channel nonlinearities, hinting that a dispersion coefficient beyond approximately ± 80-100ps/nm/km may not be extremely beneficial in terms of performance margin available from intra-channel nonlinear compensation, compared to linear

#174909 - $15.00 USD Received 4 Sep 2012; revised 30 Oct 2012; accepted 30 Oct 2012; published 11 Feb 2013

compensation only. Nonetheless at 80ps/nm/km of local dispersion (both ± coefficients), more than 2dB improvements are observed, compared to conventional standard single-mode fibre (17ps/nm/km).

In this regime of high dispersion even greater benefits are enabled by SC-DBP, as shown in Fig. 3(a). This can be attributed to the compensation of the increased intra-channel nonlinear effects at high local dispersion by the SC-DBP, allowing greater inter-channel benefit from reduced phase-matching. In particular, with a local dispersion of ± 80ps/nm/km, Q-factor may be improved by 3.5dB, compared to that of standard single-mode fibre (17ps/nm/km), hinting that commercially available negative dispersion fibres (with slightly higher loss than 0.2dB/km) may be deployed with a net performance benefit, e.g. IDF-45E [21]. Figure 3(b) shows the direct benefit of enabling SC-DBP, with up to 5.5dB improvements in Q-factor over the LC performance at ± 80ps/nm/km of local dispersion. Note that the performance improvements are largely consistent with analytical predictions of [1], except in the very-low dispersion regime (inter-channel parametric process dominate due to extreme phase-matching) where the approach of [20] should be adopted to predict the performance. One may argue that a high dispersion coefficient may result in increased complexity of SC-DBP. However, recently proposed correlated [22, 23] and folded [24] DBP may be effectively employed to take dispersion into account. Also, pre-dispersed spectral inversion has been demonstrated which may offset any complexity associated with receiver electronics [25].

3.3 Impact of dispersion management

In the previous sections, we evaluated the performance enhancements enabled by intra-channel nonlinear compensation in optical mesh networks specifically designed for coherent transmission, with no in-line dispersion compensation. Commercially deployed legacy links are largely dispersion-managed, due to their improved tolerance towards fiber nonlinearities for 10/40-Gb/s systems employing on-off keyed and/or differential phase shift keyed modulation schemes. In this section, we extend the analysis of mesh network topology considered previously, and quantify the benefits of both linear and intra-channel nonlinear compensation in dispersion-managed links.

Figure 4(a) shows the performance of central test-channel, PM-16QAM (co-propagating with PM-4QAM channels, launch power of all the channels fixed at 0dBm), as a function of in-line dispersion compensation ratio, with and without dispersion pre-compensation, after 2,400km transmission. As it can be seen, for any given configuration (using LC or SC-DBP), the transmission performance deteriorates with increasing in-line dispersion compensation, due to enhanced inter-channel phase-matching. For all in-line compensation ratios, pre-compensation enables slightly improved performance, although this is only significant at the highest dispersion compensation ratio (close to the dispersion map of legacy 10-Gb/s WDM systems). As shown in Fig. 4(b), the performance improvements enabled by SC-DBP, increases monotonically with in-line dispersion compensation ratio, and the impact of pre-compensation is more readily observed. We believe that the increasing benefit of SC-DBP with dispersion management is due to the compensation of the intra-channel nonlinear effects. With ideal receiver dispersion compensation, in-line dispersion compensation enhances both inter- and intra- channel nonlinearity through improved nonlinear phase matching and also per span restoration of the peak-to-average-power ratio, reducing the performance as shown in Fig. 4(a). This leads to reduced performance of both LC and SC-DBP, however the relative performance improvement is bigger because LC cannot compensate worsened intra-channel effects, however SC-DBP enables the intra-channel nonlinearity to be compensated, reducing the penalty associated with intra-channel effects. However, the system remains dominated by inter-channel effects, and so the total removal of dispersion management remains the most efficient means to improve system performance. Also, note that, pre-compensation causes less net improvement because in this case, the PAPR is reduced (also reduced phase matching), effectively minimizing intra-channel nonlinearities. It is worth mentioning that despite the significant work simplifying nonlinear compensation for dispersion managed systems [24, 26, 27], we find that LC of a dispersion compensation free link outperforms a strongly dispersion managed link, even with ideal DBP.

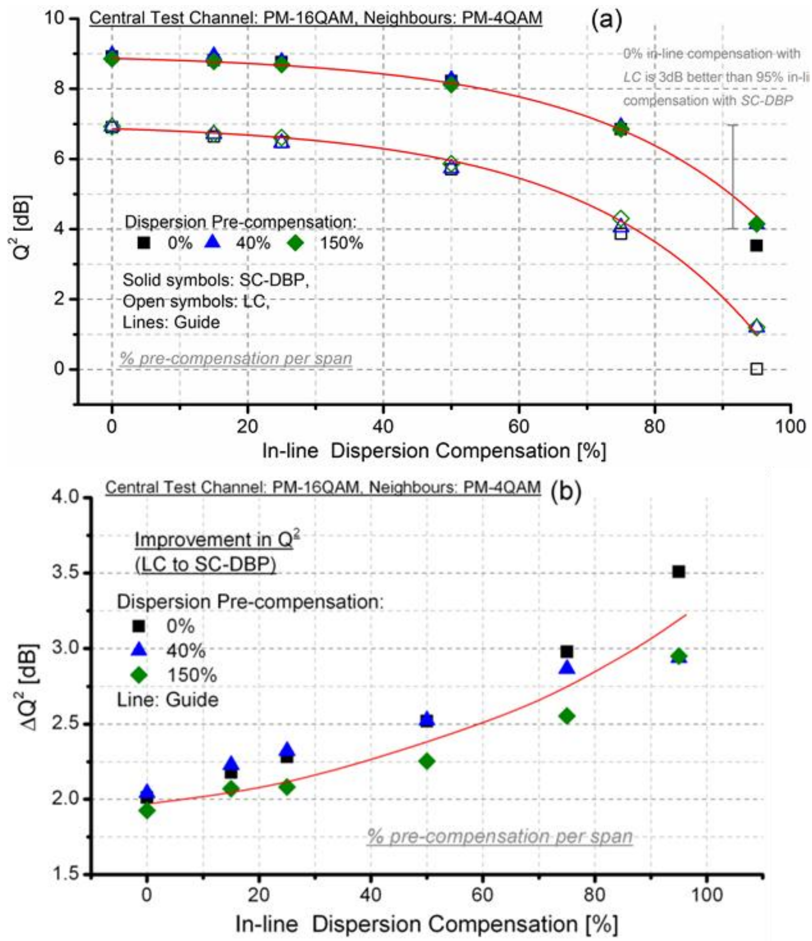

Fig. 4. (a) Q^2 of PM-16QAM channel (with PM-4QAM neighbours), fixed network power of 0dBm for all channels, versus in-line dispersion compensation ratio, after 2,400 km transmission. Squares: 0% dispersion pre-compensation, Triangles: 40% dispersion pre-compensation, Diamonds: 150% dispersion pre-compensation. Solid symbols: SC-DBP, Open symbols: LC, Lines: guide. (b) Relative Q^2 improvement from LC to SC-DBP for scenarios in (a).

4. Conclusions

We have demonstrated that in practical meshed network configuration employing 28Gbaud PM-mQAM transponders, advantages of intra-channel nonlinear compensation are significantly beyond conventionally thought bound of ~1-2dB. In particular, we have shown that in an inhomogeneous traffic scenario, intra-channel nonlinearity compensation may significantly improve the nonlinear tolerance up to 4dB for PM-16QAM through traffic, irrespective of modulation order of the co-propagating traffic, and even greater performance enhancements (up to 5.5dB) with increasing local link dispersion. Finally, we have shown that the performance improvement after intra-channel nonlinear compensation increases with in-line dispersion compensation ratio.

#174909 - $15.00 USD Received 4 Sep 2012; revised 30 Oct 2012; accepted 30 Oct 2012; published 11 Feb 2013

Acknowledgments

This work was supported by Science Foundation Ireland under Grant numbers 06/IN/I969 and 08/CE/11523. We would like to thank N.J. Doran for useful discussions.