FIELD VERIFICATION OF 40G DPSK UPGRADE IN A LEGACY 10G NETWORK

Valey Kamalov, Bikash Koley, Xiaoxue Zhao and Cedric F. Lam
Google, Inc. 1600 Amphitheatre Parkway, Mountain View, CA 94043 USA
{vkamalov, bkoley, wendyzhao, clam}@google.com

Abstract: We report verification of 1,200 km field upgrade of 10G NRZ wavelengths with 40G DPSK channels. Non symmetric dispersion map results in pronounced intra-channel nonlinear effect, which could be significantly reduced by dispersion pre-compensation.

OCIS codes: (060.0060) Fiber optics and optical communications; (060.2330) Fiber optics communications

1. Introduction

Compared to the conventional 10Gb/s technology, 40Gb/s per channel transmission brings a number of challenges due to shorter pulse width and consequently reduction in the tolerances for OSNR, chromatic dispersion, and PMD. Besides, the greater signal bandwidth results in transmission penalty when 40Gb/s wavelengths are passed through narrow-bandwidth wavelength selective switches. The propagation of short 40Gb/s chirped pulses through 1,000+ km of fiber is also characterized by nearly completely overlapped bits due to chromatic dispersion [1]. Dispersion management of 40Gb/s signals becomes quite different compared to the conventional long-haul 10Gb/s transmission engineering rules. The pulse-to-pulse interaction resulted from chromatic dispersion gives rise to intra-channel cross-phase modulation (IXPM) and intra-channel four-wave mixing (IFWM). It has been shown [2] that pulse-overlapped dispersion managed transmission is characterized by smaller (in comparison with nonoverlapped and partially overlapped regime) pulse derivative, which also changes sign across the region of overlap. Strong overlapping thus reduces inter-channel XPM induced pulse-to-pulse interaction. However, IFWM adds ghost pulses due to the interaction of Kerr nonlinearity and chromatic dispersion and becomes the limiting factor for pulse overlapping transmission.

In [3] Ho derived a semi-analytical method to evaluate the error probability due to IFWM for 40Gb/s DPSK optical communication systems, and Wei et al [4] studied nonlinear penalties due to IFWM in highly dispersed transmission for both symmetric and nonsymmetric dispersion maps. They showed that amplitude phase shift vanishes when the dispersion map is symmetric [5], while a differential phase shift remains both in symmetric and non-symmetric dispersion.

In this paper, we demonstrate improved 40Gb/s DPSK performance with symmetric dispersion map in a 1,200-km field trial on a live network. We show that chromatic dispersion management is a major issue when upgrading conventional 10G OOK (On-off keying) transmission system with 40G DPSK (Differential phase-shift keying) channels. While the difference in the optimal residual dispersion value between 10G and 40G channels could be compensated by tunable dispersion compensation modules inside 40G line cards, managing the IFWM requires adjustment of inline dispersions to produce a nearly mirror-symmetrical dispersion map with respect to 0 dispersion.

2. Google Long Haul Fiber Field Test Configuration

The Google meshed LH network selected for this field test (Fig.1) was originally deployed with 80 channels of 10 Gbps NRZ OOK wavelengths on 50 GHz ITU grid. High volume of traffic filled 80% of the deployed 0.8 Tbps capacity. 40G upgrade would increase the network capacity to 3.2 Tbps. The particular field trial configuration is shown in Fig.1, only three channels in the transparent meshed network were available for 40G upgrade between Metro 3 and Metro 4: two at the edges of the C-band, and the third one at the center. Spectral positions of 40G DPSK channels are shown in the Fig. 2 together with co-propagating 10G channels.

Optical path between Metro 3 and Metro 4 consists of 1200-km mixed types of LEAF and SMF-28 fibers. Out of the total 12 spans, nine were LEAF and three SMF-28. 15 EDFAs and two Raman amplifiers were deployed in the link, which also includes two WSSs with FWHM of 43 GHz. Five spans were over 100 km, with two spans having high loss of 35 dB and 32 dB, where both EDFA and Raman amplifiers were employed. The 40G channels at 193.65 THz and 191.7 THz had OSNR values around 17-18 dB in both directions, while channel 196.1 THz at the high frequency edge of C-band had a lower OSNR around 14-15 dB. Relative values of OSNR for each channel for both directions were within 1 dB. Narrow chromatic dispersion tolerance of 40G DPSK transmission requires fine tuning of CD to within 100 ps/nm window, which was performed by the built-in adaptive dispersion compensator inside the 40G card. Adaptive feedback was based on the pre-FEC BER of 40G channel, which was proven to be a reliable way to automatically adjust and maintain the chromatic dispersion at the optimal value.

978-1-55752-884-1/10/$26.00 ©2010 IEEE

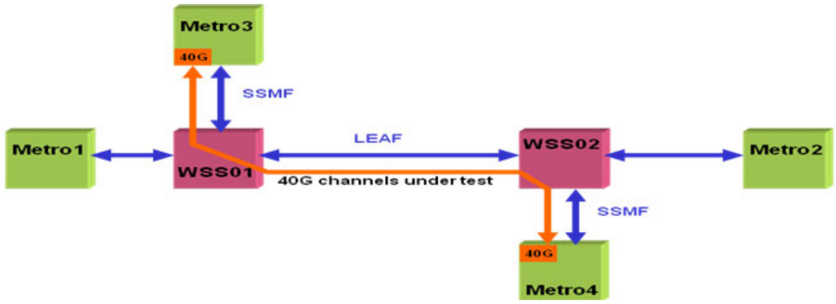

Figure 1. Part of Google 10G optical meshed network. Distance between Metro 1 and Metro 2 is 2,000 km. Optical path between Metro 3 and Metro 4 (used for 40G transmission) is 1,200 km . Wavelength selective switches WSS01 and WSS02 are reconfigurable OADMs with bandwidth of 43 GHz

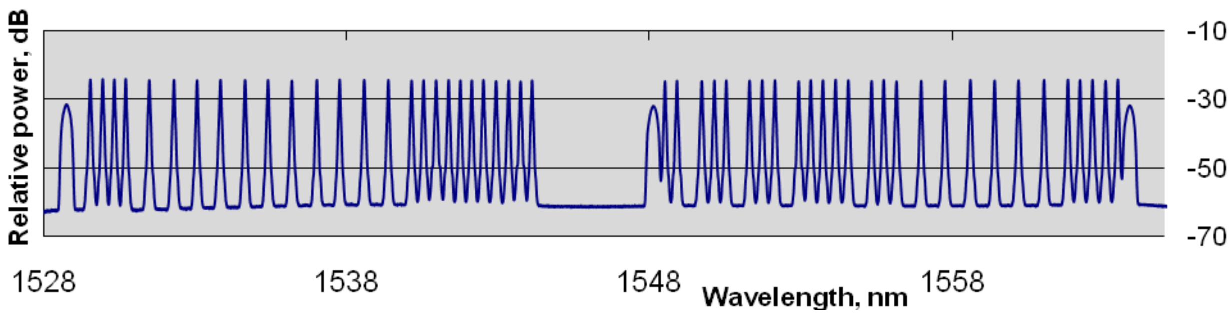

Figure 2. Transmitted spectrum at Metro 3. The channels at 1528 nm, 1548 nm, and 1563 nm are 40G DPSK, the rest are 10G NRZ OOK channels.

Dispersion compensation fiber (DCF) was employed between two-stage EDFAs to compensate chromatic dispersion. The original dispersion maps in the two opposite directions were different. From Metro 4 to Metro 3, 85-90% inline compensation was applied, which had near mirror-symmetry relative to 0 dispersion. In the opposite direction from Metro 3 to Metro 4, the dispersion map had strong imbalance towards the positive dispersion regime. Nine spans of LEAF between WSS01 and WSS02 had accumulated dispersion over 1,000 ps/nm. Fixed post-compensation was used at the end of the link. The design target was to bring cumulative dispersion at the end of the link to 0 ps/nm for all channels. In reality, the net residual dispersion spreaded over 700 ps/nm, mostly due to slope mismatch for LEAF section of the transmission link and the limited granularity of DCF modules.

3. Results and Discussion

Fig. 3 shows performance of the 10G channels for both directions connecting Metro 3 and Metro 4. All sixteen 10G channels had pre-FEC BER between 10^{-7} and 10^{-8} , independent of the different dispersion maps in the two directions. Fig.3 also shows the performance of the 40G channels traversing on the link from Metro 4 to Metro 3 with mirror-symmetric dispersion map. The pre-FEC BER for the 40G channels from Metro 4 to Metro 3 was around 10^{-5} for all three wavelengths tested, and required no further dispersion adjustment.

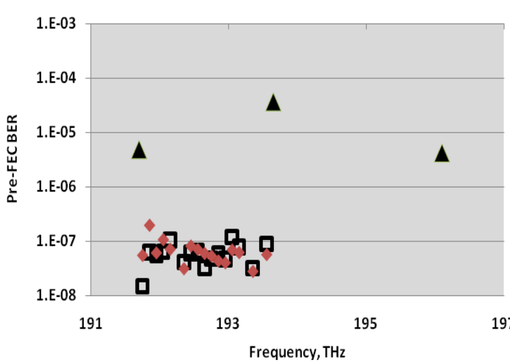

Figure 3. Performance of 10G (squares) and 40G (triangles) channels from Metro 4 to Metro 3 direction (with mirror-symmetric dispersion map) and 10G (diamonds) channels from Metro 3 to Metro 4 (nonsymmetric map).

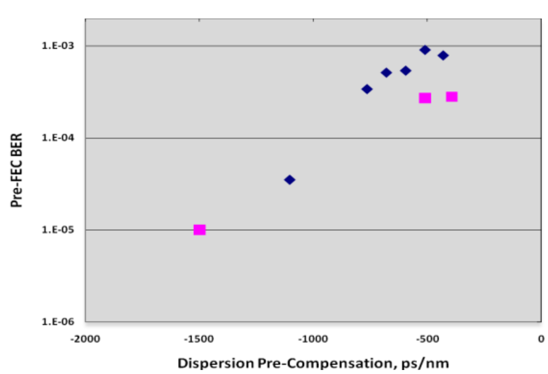

Figure 4. Pre-FEC BER vs chromatic dispersion pre-compensation for 40G channels traversing from Metro 3 to Metro 4: Channel 193.65 THz (diamonds) and Channel 191.7 THz (squares)

Without adjusting dispersion pre-compensation, the pre-FEC BERs of the channels from Metro 3 to Metro 4 ($1x10^{-3}$ for 196.1 THz, $9x10^{-4}$ for193.65 THz and $3x10^{-4}$ for 191.7 THz 40G channels) were barely exceeding the FEC threshold of $2x10^{-3}$. The significant performance difference between the two directions could not be explained by OSNR, which was within 1 dB of each other. Additional per channel pre-compensation was then applied to 40G channels from Metro 3 to Metro 4. Fig. 4 shows the dependence of pre-FEC BER on the value of pre-compensation for Channel 193.65 THz (blue diamonds) and Channel 191.7 THz (red squares). Tuning pre-compensation in this direction resulted in considerable transmission quality improvements. Both 40G channels shown in Fig. 4 achieved pre-FEC between 1 $x10^{-5}$ and $3x10^{-5}$ when pre-compensation between -1,000 ps/nm and -1,500 ps/nm was applied.

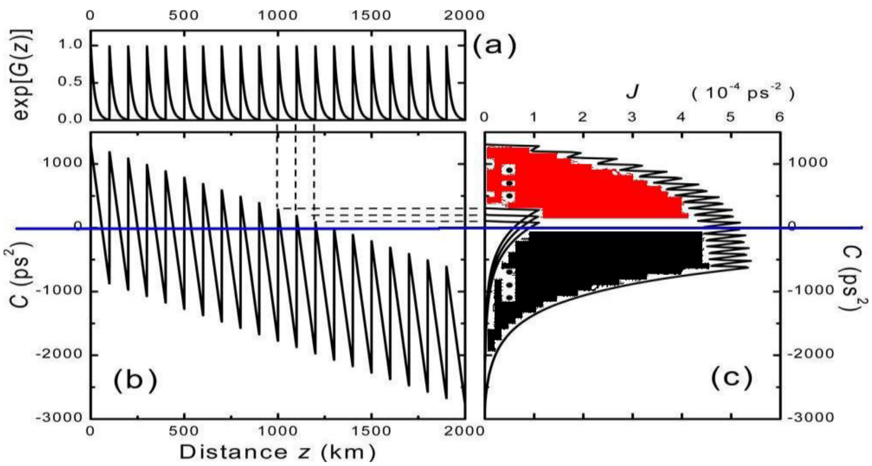

Figure 5 (from X.Wei [6]). Example of multi-span transmission system. (a) Power profile, (b) cumulative dispersion, and (c) power - weighted dispersion distribution function. The contribution from a few individual spans also shown in (c).

We attribute the improvement to the reduction of intra-channel four-wave mixing, whose effect can be characterized using a power-weighted dispersion distribution function J(C) [6], where C stands for cumulative dispersion. Each span contributes to J(C) a single-sided exponential decay function exp(G(z)), which is accumulated loss/gain profile (see Fig. 5a). These individual functions are staggered to form a broader function J(C), which is constructed as the Fourier transform of the nonlinear transform function and provides helpful insight into the effect of dispersion mapping in 40G transmission. Pre-compensation essentially works as a parameter changing the accumulated nonlinear phase, thus helping us to find the sweet spot for optimal 40G performance. The value of pre-compensation should be chosen so that positive and negative portions of C in Fig.5b have roughly equal weight, or $\int_{-\infty}^{0} J(C)dC \approx \int_{0}^{+\infty} J(C)dC$, for optimal transmission performance [6]. In Fig.5c we show red/black filled positive/negative portion of weighted J(C), which have roughly equal weight for optimal nonlinear performance. In our field trial, additional pre-compensation was added on a per-channel basis. The positive and negative portions of the weighted dispersion roughly balanced out with about -1,500 ps/nm pre-compensation.

In conclusion, we carried out successful 1,200 km field verification of 40G DPSK upgrade in a legacy 10G live network. Non-symmetric dispersion map results in pronounced intra-channel nonlinear effect, which could be significantly reduced by dispersion pre-compensation.

Acknowledgements: The authors would like to thank Andrzej Kaminski, Michel Chbat, David Stahl, and Gottfried Lehmann for their helps and supports.

References

[1] R.-J. Essiambre, G. Raybon, B. Mikkelsen, "Pseudo-Linear Transmission of High-Speed TDM Signals: 40 and 160 Gb/s" in *Optical Fiber Telecommunications IV*, Vol. B, pp 232304, Academic Press, 2002.
[2] P.V. Mamyshev, N.A. Mamysheva, Opt. Lett., **24**, p.1454 (1999)
[3] K.P. Ho, IEEE Photon. Technol. Lett. **17**, 789 (2005).
[4] X. Wei, X. Liu, S. H. Simon, C. J. McKinstrie, Opt. Lett. **31**, 29 (2006)
[5]A. Mecozzi, C. B. Clausen, M. Shtaif, Sang-Gyu Park, A. H. Gnauck, IEEE Photon. Technol. Lett., **13**, 445 (2001)
[6] X. Wei, Opt. Lett., **31**, 2544 (2006)