Upgrades of Medium Haul Submarine Systems to 40 Gb/s

Sumudu Edirisinghe (1), Wai Wong (1), Jörg Schwartz (1), Supriyo Dey (2), Steve Penticost (2)
1: Xtera Communications, Bates House, Church Rd, Romford RM3 0SD, UK, Email: joerg.schwartz@xtera.com
2: Mintera Corporation, 35 Nagog Park, Acton, MA 01720, USA

Abstract

This paper discusses how commercial 40 Gb/s transponders can be used for upgrades of medium haul submarine links by taking into account dispersion optimisation requirements and co-existing channels.

Introduction

Terrestrial backbone networks are being widely upgraded to 40 Gb/s line rate. For transoceanic submarine systems, however, this is still a very challenging prospect [1-3].

Generally, application of a 40 Gb/s line rate is attractive for operators because fewer channels need to be managed and usually an increase in bit-rate comes with lower overall equipment costs [4].

Although various proposals have been made for the overall design of new-build submarine systems, upgrades of existing systems offer greater challenges because their line design was never intended for 40 Gb/s transmission.

Undersea systems typically use non-zero dispersion shifted fibre (NZDSF) in conjunction with standard single mode fibre (SSMF) for in-line dispersion compensation. The dispersion wavelength-dependence of these two fibres has the same sign and magnitude. This leads to incomplete compensation of WDM channels close to the band edges. In addition, transmission performance is degraded due to the dispersion variation within the spectral width of the 40 Gb/s channel. These effects, together with PMD and nonlinear penalties, impose the main limitations on the application of 40 Gb/s on transoceanic systems [2,3].

Various geographical areas in the world would significantly benefit from 40 Gb/s upgrades of amplified medium haul undersea systems (i.e. up to ~3000 km length) by providing homogeneous 40 Gb/s networks in conjunction with terrestrial backbones.

This paper investigates whether or not and under what operational regimes this is possible. It also addresses two of the main questions for such applications: how to deal with the special dispersion maps of submarine systems and what is the impact of existing 10 Gb/s channels, which often remain in operation after an upgrade.

Transmission setup and performance

The first target was to confirm whether medium haul systems, originally designed for 10 Gb/s ASK, can be addressed using commercially available 40 Gb/s DPSK transponders, which in linear terms, requires an extra ~3 dB in signal-to-noise ratio (OSNR). Although the amplifier spacing of amplified systems is increased on shorter systems to give a certain target OSNR, typically installed systems have unused margins that can be employed.

This was reflected in the testbed used, which consisted of a 2013 km straight line with typical 70 km optical amplifier spacing. Each span consisted of NZDSF fibres with -2 ps/nm/km dispersion at 1550 nm. At the input of each span, approximately 25 km of larger core area (70 μm^2) fibre was used. Its higher slope was compensated by reduced slope fibres to give an average dispersion slope of 0.08 ps/nm^2/km.

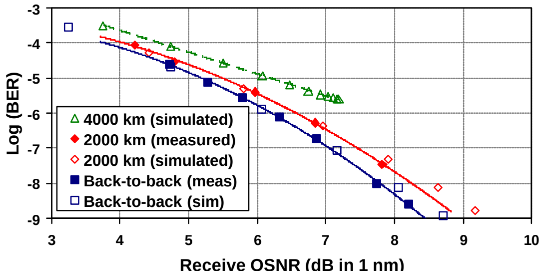

Figure 1: 40 Gb/s error performance, back-to-back, after 2000, and 4000 km transmission

The Erbium doped fiber amplifiers had a flat bandwidth of 20 nm between 1543 nm to 1563 nm and a noise figure of less than 6 dB. The average launch power into each span was +10 dBm. The measured performance of a 42.7 Gb/s test channel operating at 1555.75 nm and utilising light P-RZDPSK modulation [5], a filter tolerant variant of RZ-DPSK, is shown in Fig. 1. This evaluation, which was confirmed and extended by computer simulations, suggests that the maximum transmission distance is limited to approximately 4000 km with standard margins for the line design investigated.

The 40 Gb/s channel was transmitted with 4 loading channels spread across the bandwidth, which were adjusted to ensure the 40 Gb/s channel was operating in its normal power regime of typ. -3 dBm.

Dispersion map dependence and optimisation

The testbed included SSMF spans after every sixth NZDSF span to compensate periodically for the line dispersion. The SSMF span lengths of 70 km were reduced by 10 and by 20 km in separate tests to evaluate the impact of the dispersion map on the

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system performance. In addition, transmission was measured in the opposite direction as a fourth case (Fig. 2, upper)

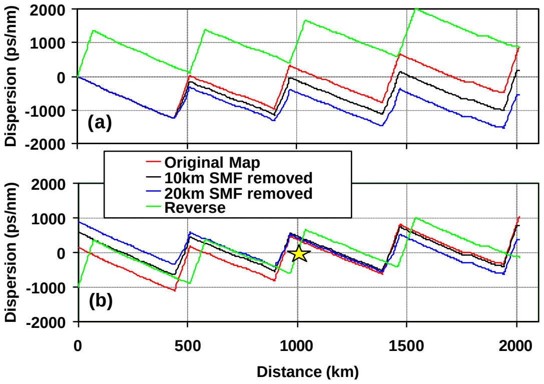

Figure 2: Dispersion map variations by changing the lengths of SSMF used for in-line compensation. (a) Initial maps without pre-compensation and (b) with optimum pre-compensation applied

Due to the large strength of the dispersion map (>4), the modified (i.e. under-compensated) maps also give a good indication about the performance in different wavelength regions, although the transponder wavelength was not swept for these experiments.

To optimise performance, the dispersion pre- and post-compensation of the test channel was optimised for all 4 dispersion maps (Fig 2, lower). The detailed results shown in Fig. 3 are in good agreement with computer simulations; the shift on the y-axis is due to the fact the noise loading was applied.

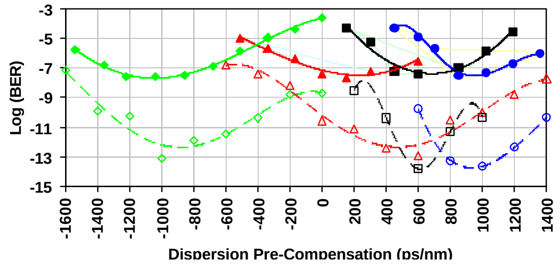

Figure 3: Measured (solid) and simulated (dashed/ open) pre-compensation optimisation for different dispersion maps. The colours correspond to Figure 2.

The strongly map-dependent minima show that pre-compensation and its optimisation is absolutely essential even for shorter system lengths. The approach of using post compensation only for 10 Gb/s over 2000 km is, therefore, not viable here [3] and would lead to penalties of several orders of magnitude in BER.

It should also be noted that the ratio of pre- and post-compensation strongly depends on the shape and slope of the dispersion map and not only on the end-to-end residual dispersion. Further simulations of this behaviour led to the conclusion that, as a rule, the performance of all different maps converge to an optimum if the effective map is made symmetrical around the 50% distance point (1007 km in this case) by applying adequate pre-compensation (Fig. 2b).

Mixed bitrate overlay performance

In a normal upgrade scenario, 10 Gb/s and 40 Gb/s channels are likely to be placed next to each other. Their interaction was investigated by putting 4x10 Gb/s ASK channels at either side of the 40 Gb/s DPSK test channel, which was 3 dB higher in power; all were randomly polarised. The pairs of 10 Gb/s channels were 50 GHz spaced and their distance from the 40 Gb/s channel was varied symmetrically.

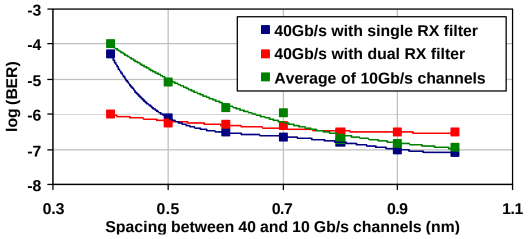

Figure 4: Spacing dependent performance degradation of neighbouring 10 & 40 Gb/s channels

Figure 4 shows that the BER of the 10 Gb/s channels (with 0.25 nm receiver filters) deteriorated when the channel spacing was reduced below 1 nm. The 40 Gb/s channel suffered only a 0.5 dB penalty up to 75 GHz spacing. Channels can be moved even closer to the 40 Gb/s channel if tighter filtering is applied, e.g. by concatenating two 0.4 nm receiver filters.

Conclusions

Upgrades of submarine systems to 40 Gb/s using commercially available transmission equipment can be feasible for spans up to 4000 km given the correct conditions. The dispersion must, however, be compensated not only at the receiver (as is usual for terrestrial systems), but also at the transmitter. A rule has been presented to pre-select the appropriate value for different maps and wavelengths.

When adding 40 Gb/s channels to a system carrying 10 Gb/s channels, the channel spacing can be reduced below 1 nm only if the penalty is acceptable for the 10 Gb/s channels.

Acknowledgements

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