HIGHER BITRATES AND ADVANCED MODULATION FORMATS FACILITATE OVERLAY UPGRADES OF INSTALLED SUBMARINE SYSTEMS

Jörg Schwartz, Steve Webb, Stuart Barnes
joerg@azea.net
Azea Networks Ltd., Bates House, Harold Wood, Romford RM3 0SD, United Kingdom
Ronald Freund, Lutz Molle, and Christoph Caspar
Ronald.Freund@hhi.fraunhofer.de
Fraunhofer-Institute for Telecommunications, Heinrich-Hertz-Institut, Einsteinufer 37, 10587 Berlin, Germany.

Abstract: Upgrades of undersea communication systems beyond their design capacity is an attractive alternative to deploying new cables. Increasing the per wavelength channel bitrate is an obvious way to facilitate this. Nevertheless, this comes with tightened performance requirements, such as improved noise and dispersion tolerance, which will reduce any available margins. Applying new modulation formats is a route to mitigate these effects. This paper discusses the technical challenges for carrying out upgrades, either as overlays or on dark fibres, and also presents recent research results on how to add capacity to systems currently operating with N×10.7 Gbit/s RZ-ASK signals over transoceanic distances. Experiments and simulations are used to analyse performance and limitations, with 20 Gbit/s RZ-DPSK being a strong candidate for upgrades.

1. INTRODUCTION

Upgrades of telecommunication systems using existing fibres have become a very interesting proposition for carriers since it allows stepwise, low cost, and small granularity increases of the network capacity. Although not relevant for terrestrial links, the concept of upgrades has attracted a lot of attention for long-haul undersea systems. Previously, upgrades were mainly considered as adding WDM channels to an under-equipped system up to the design capacity. However, since first reports on how today's technology can be utilised to upgrade legacy systems, e.g. in [0], the concept of stretching the capacity beyond the original design limits has been adopted in commercial deployments for submarine systems.

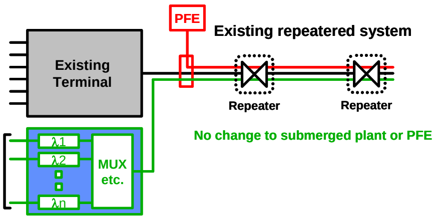
Systems of the first and second generation, designed for single channel, 2.5 or 5 Gbit/s, and N×2.5 Gbit/s WDM operation, respectively, are upgraded by increasing the bitrate to 10 Gbit/s and/or increasing the channel number. However, more recently third generation systems have been designed for N×10 Gbit/s utilising a narrow spaced DWDM grid. Therefore taking those systems beyond their original design capacity by adding channels often represents a challenge. Options of upgrades by increasing the bitrate per channel are studied in this paper.

2. DARK FIBRE VS. OVERLAY UPGRADES

Upgrade has become a widely used, and often confusing, term and in fact there are a variety of approaches. The most straight- forward approach is a so-called dark fibre upgrade (s. Fig. 1). However, this requires an unused fibre pair to be available or existing channels to be removed and re-routed before the upgrade can be performed. Dark fibre upgrade scenarios using N×40 Gbit/s using Differential Phase Shift Keying (DPSK) modulation on non-slope matched undersea fibre spans, have already been proposed [0,0].

However, most recently a side-by-side comparison of 10 Gbit/s and 40 Gbit/s RZ-DPSK using the same spectral efficiency over transoceanic distances showed 1 dB less margin for 40 Gbit/s, with further reduction due to significantly worse performance fluctuations [0].

Another upgrade option involves adding new channels by a (new or already existing) coupler. This has the benefit that existing traffic remains largely unaffected. This approach limits the maximum achievable capacity since the power of newly added channels is limited by the margins available on the existing ones. Furthermore, mixing bitrates and modulation formats on the same fibre can also lead to penalties by channel interactions [5].



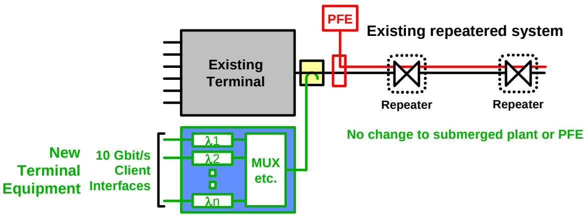


Figure 1: Dark fibre (upper) vs. overlay upgrades (lower).

3. DPSK FOR OVERLAY UPGRADES

For experimental studies of both 10 Gbit/s RZ-ASK and 40 Gbit/s RZ-DPSK a re-circulating fibre twin-loop testbed (s. Fig. 2) using non-slope matched submarine fibres was used. This offers high flexibility and allows replication of the dispersion and OSNR maps of typical transoceanic submarine links.

Four Erbium Doped Fibre Amplifiers (EDFA) with characteristics similar to submarine line amplifiers were used to compensate for the fibre attenuation and insertion loss of the loop components. In addition, the loop contained two Fibre Bragg Grating (FBG) based notch filters to suppress Amplified Spontaneous Emission (ASE) noise peaks. The output power of the EDFAs was adjusted to about +9 dBm total launch power into both the Non-Zero Dispersion Shifted Fibre (NZDSF) section and the standard Single-Mode Fibre (SMF) sections. Different NZDSF fibre variants, including large effective area fibre (LEAF) and low-slope fibre were selected to give a good representation of a Generation 3 system.

The power of the WDM channels was equalised using a channel-based dynamic Gain Equaliser (GEQ) in the inner as well as a two-stage Mach-Zehnder based gain Equaliser (MZ-EQ) in the outer loop. Polarisation scrambling (~ 700 kHz) was applied to mitigate polarisation effects. The sixteen launched WDM channels (1546.12… 1558.17 nm) were co-polarised (representing the worst case) and modulated with PRBS of length 2^{23}-1.

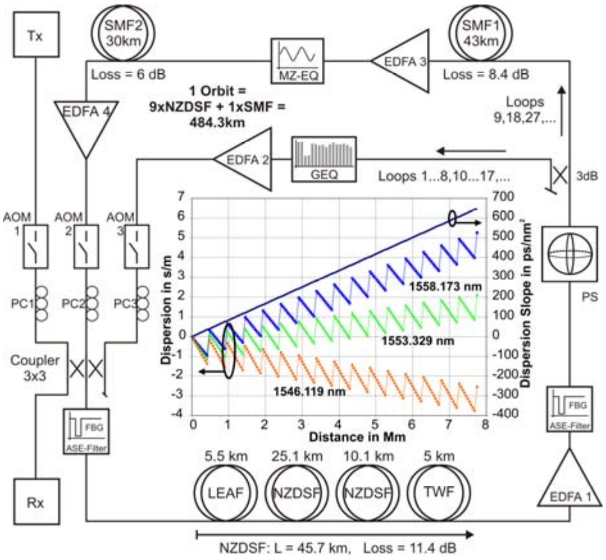


Figure 2: Twin-loop configuration and dispersion map.

As a reference point, the transmission performance of 16×10.7 Gbit/s RZ-ASK was evaluated using a proprietary submarine transponder. As shown in *Figure* 3 the signal was transmitted over 6000 km with a BER ~10^{-8} without use of additional phase modulation (chirp).

To emulate an upgrade using commercial 40 Gbit/s technology, the 1553.33 nm channel was then replaced by a 42.8 Gbit/s RZ-DPSK modulated signal. From the OSNR of ~7 dB/nm after 6000 km and the noise-loaded back-to-back performance at 42.8 Gbit/s one would have expected a BER of about 10^{-7}, however only a value of ~5×10^{-4} was observed (see *Figure* 3) – which is above the level of 1×10^{-6} (Q = 13.5 dB) typically required for operating a system using enhanced Forward Error Correction (FEC) with sufficient margins.

Furthermore, loop experiments are likely to give optimistic performance values in the context of Polarisation Mode Dispersion (PMD) as it is highly likely that the loop has better PMD characteristics than some of the worst field deployments.

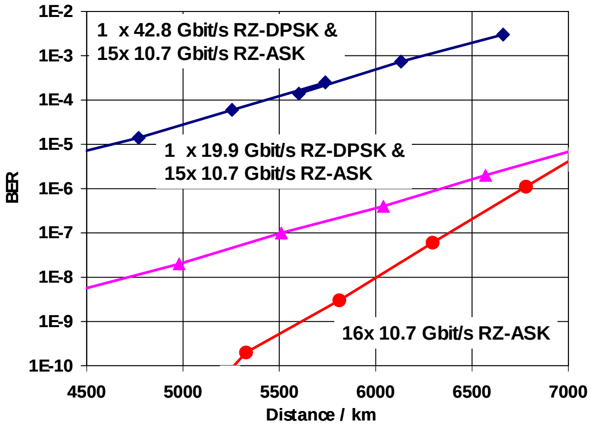


Figure 3: Measured BER vs. distance for different upgrade scenarios for 100 GHz channel spacing.

4. 40 GBIT/S SYSTEM MODELLING

The results of the 40 Gbit/s experiments were compared to numerical simulations. First the spectrum and the waveform of the launched 42.8 Gbit/s RZ-DPSK signal were approximated by choosing the appropriate drive signal and modulator parameters (s. Fig. 4).

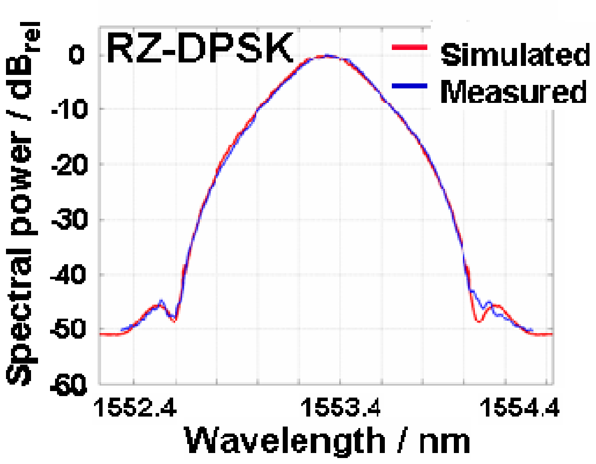


Figure 4: Measured and simulated Spectrum at transmitter output for 42.8 Gbit/s RZ-DPSK.

The back-to-back performance of the experimental transmitter and receiver units were calibrated by proper selection of the optical and electrical filter bandwidths. Figure 5 shows the comparison of the simulated and measured back to back performance as well as the comparison of a measured and simulated eye diagram after balanced detection.

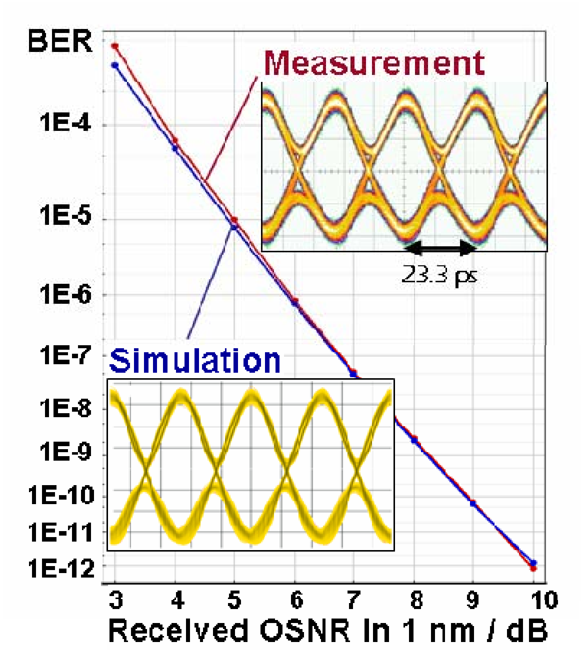


Figure 5: Measured and simulated back-to-back performance of the 42.8 Gbit/s RZ-DPSK system.

Thereafter the OSNR performance of the transmission link was approximated by proper selection of the EDFA's noise figure (s. Fig. 6).

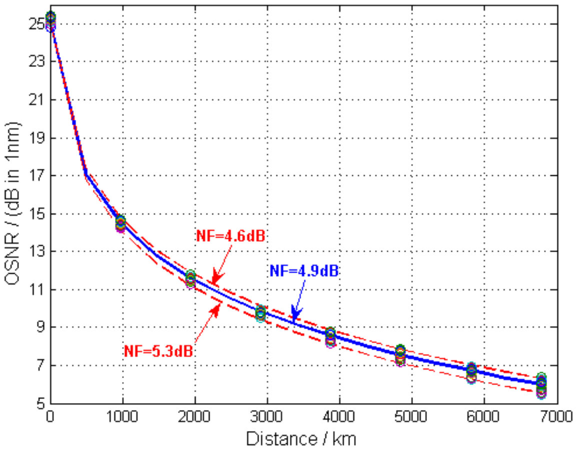


Figure 6: Comparison of linear link performance. Circles show measured OSNR for a 16 channel WDM comb. Lines show OSNR vs. distance approximation.

After approximation of the linear link performance the influence of the Kerr effect was investigated for single channel transmission. Figure 7 shows the comparison of the measured and simulated link performances, which are in good agreement. Numerical simulations show more then one decade BER improvement by applying in-band dispersion slope compensation after 6500 km. This is promising but requires further experimental investigation. For system upgrades, in-band dispersion slope compensation can only be applied at the terminals since modifications of the installed submarine fibre plant are undesirable.

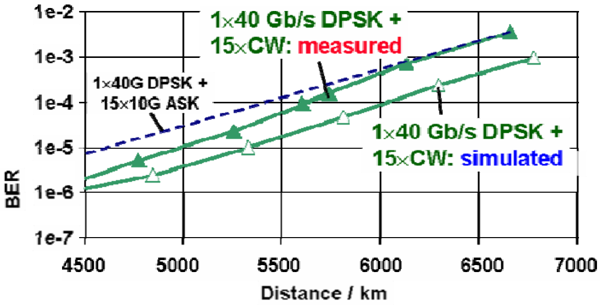


Figure 7: Comparison of measured and simulated link performance for 1×42.8 Gbit/s transmission without in-band slope compensation of chromatic dispersion.

5. 20 GBIT/S VS. 40 GBIT/S

As an alternative approach to enhance the design capacity, one 10 Gbit/s RZ-ASK channel was upgraded to 20 Gbit/s RZ-DPSK (*Figure* 3). Without needing in-band dispersion slope compensation and even with a non-optimised receiver the 20 Gbit/s channel showed less performance degradation and sufficient margins at 6000 km. Furthermore, the 20 Gbit/s performance converged towards the 10 Gbit/s BER at longer distances.

The maximum spectral efficiency achievable with 20 Gbit/s RZ-DPSK was investigated by reducing the channel spacing. In contrast to the 40 Gbit/s experiments, 3 channels were substituted by 20 Gbit/s RZ-DPSK with variable spacing. In this case, the remaining channels were left unmodulated.

The results (s. Fig. 8) show that the channel separation can be reduced to 50 GHz until the onset of significant performance degradations. This is of course directly relevant for dark-fibre upgrades and promising for overlay scenarios. A channel spacing reduction from 100 GHz to 50 GHz relates to a BER degradation of less than 1 decade (Q degradation of < 0.4 dB) at 6000 km. Comparing to the 40 Gbit/s WDM experiments, the same spectral efficiency of 0.4 bit/s/Hz was achieved using 50 GHz spaced 20 Gbit/s RZ-DPSK at 6000 km – but with about 4 orders of magnitude lower BER.

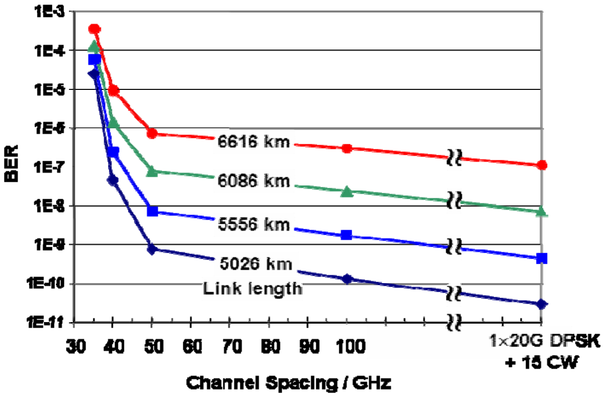


Figure 8: Measured BER vs. channel spacing at different transmission distances.

6. CONCLUSIONS

Upgrading existing submarine links beyond their design capacity using 40 Gbit/s technology turns out to be difficult and expensive task and still results in marginal Q performance. On the other hand, 20 Gbit/s RZ-DPSK is a promising candidate for upgrading non-slope matched transoceanic transmission systems. It does not require in-band dispersion slope compensation and for longer distances it offers performance comparable to 10 Gbit/s RZ-ASK – but with twice the spectral efficiency.

7. REFERENCES

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