TOWARD LOW-COST HIGH-SPEED SUBMARINE TRANSMISSION UPGRADES

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Abstract: In this paper, the low-cost approach for upgrading the submarine links toward 40 Gb/s and 100 Gb/s is shown. With simple optimization of submarine line terminal equipment, by varying the input power per channel and dispersion pre-compensation, several submarine distances, up to 7000 km, based on realistic data were successfully bridged. The maximum capacity × distance reach of the CP-QPSK format was found. A simple rule for future submarine links upgrades with advanced coherent formats towards 100 Gb/s transmission bit rates is proposed.

1. INTRODUCTION

With the rapid access of novel broadband services, high-speed optical transport networks are in constant demand. This is particularly challenging over the long-haul multi-span submarine distances (more than 1000 km) due to the difficult access of the transmission fibres in the wet plant. Therefore, the low-cost upgrades of submarine links towards the higher transmission capacity are preferred and it can be achieved by upgrading only the submarine line terminal equipments (SLTE) [1-2]. Current tendency leads to upgrade the legacy 10 Gb/s SLTE towards 40 Gb/s and 100 Gb/s transponder technologies. This had been achieved with the use of the coherent-detected polarization-multiplexed, quadrature phase shift keying (CP-QPSK) format, which offer many advantages including the compatibility with a 50 GHz channel grid, dispersion un-managed transmission and electronic polarization mode dispersion compensation [3-5]. However, an extended optimization and the capacity/distance limits with the coherent advanced formats over submarine links, still remain to be explored.

In this paper, the low-cost approach of upgrading the submarine links toward 40 Gb/s and 100 Gb/s is shown. With simple optimization of SLTE, by varying the input power per channel and dispersion pre-compensation over the C-band (1540-1560 nm), the 40 Gb/s and 100 Gb/s wavelength division multiplexing (WDM) transmission system with 50 and 100 GHz channel spacing and with advanced modulation format, CP-QPSK, are analyzed over 2, 4, 6, and 9 thousands km. The maximum capacity x distance submarine reach of the CP-QPSK format is calculated.

2. SYSTEM SET-UP

The WDM system with 7 channels with 100 GHz of channel spacing and 9 channels with 50 GHz of channel spacing is used to launch over the long-haul multi-span submarine distances. The setup of the transmitters used for 40 /100 Gb/s CP-QPSK generation, coherent receiver, and typical submarine link are depicted in

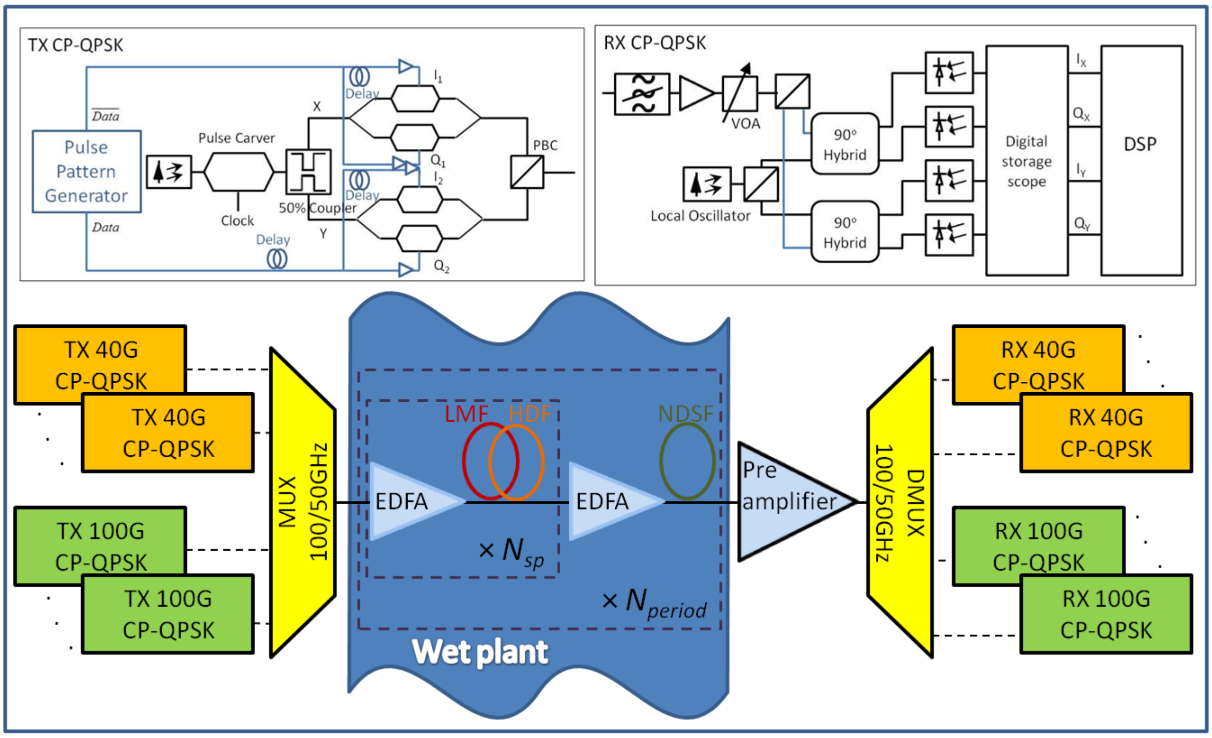

Figure 1: Setup of the investigated multi-span submarine system. ***Inset left hand side top*****: Setup of transmitter of CP-QPSK signal.** ***Inset right hand side top*****: Coherent Receiver.**

Fig. 1. The results are obtained by numerical simulations.

For the 100 Gb/s CP-QPSK transmitter the output of the laser is first return-to-zero modulated using a Mach–Zehnder modulator (MZM) driven with an 31.25 GHz clock signal. Note that for 40 Gb/s CP-QPSK, the non return-to-zero signal shape is used. The resulting signal is then split into two parts using a polarization-maintaining coupler, and each tributary is QPSK modulated using a nested MZM. The driving signals of the nested MZMs are psuedorandom binary sequences (PRBS) at a 31.25 and 11.45 GBd symbol rate generated by a pulse pattern generator (PPG) for 100 and 40 Gb/s signal, respectively. The two outputs of the PPG are delayed with respect to each other for decorrelation of the polarizations and so, split into two equally powered signals. These driving signals are again delayed with respect to each other and then fed to the in-phase (I) and quadrature (Q) port of the nested MZMs. All three delays exceeded the length of the finite impulse response filters used in the receiver-side digital signal processing (DSP). In the following, the two polarizations are combined by means of a polarization beam combiner (PBC), resulting in a 125 and 45.8 Gb/s CP-QPSK modulated signals.

Four different distances of typical repeatered submarine links were used for transmission with total length of more than: 2000, 4000, 6000, and 9000 km. Each of the links consists of the periodically compensated transmission segment as in [3]. The typical hybrid transmission span is used, which consists of two types of low dispersion fibres with total length of about 50 km and the erbium doped fibre amplifier (EDFA) to set the launch input powers at the span input. The first fibre in the transmission span is a large mode field (LMF) fibre with an effective area of > 72 μm and group velocity dispersion (GVD) coefficient of -3.9 ps/nm/km (at 1550 nm), and second fibre is high dispersion fibre (HDF) with an effective area of 50 μm and GVD coefficient of -2.7 ps/nm/km. Periodic dispersion compensation is achieved with nondispersion-shifted fibre (NDSF) with an effective area of > 75 μm and a dispersion coefficient of +20 ps/nm/km. The effective zero dispersion wavelength of the complete segments is at 1550 nm.

After transmission, the channel under test is demultiplexed and fed to the receiver depicted in inset of Fig. 1. Here, the signal is mixed with a local oscillator (LO) in a polarization-diversity 90° optical hybrid. The in-phase and quadrature components of both polarizations are then converted to the electrical domain using four single-ended photodiodes and, subsequently, analog-to-digital sampled at a 50 Gsample/s sampling rate by a digital storage scope. Samples for 45.8 Gb/s CP-QPSK, and samples for 125 Gb/s CP-QPSK are used for offline signal processing [3-4].

3. RESULTS AND DISCUSSION

The optical signal-to-noise ratio (OSNR) and required OSNR (ROSNR) are calculated for each of the system scenarios. The system margin refers to the difference between OSNR and ROSNR at certain input power / channel. The maximum system margin refers to the maximum difference between the OSNR and ROSNR at the optimum input power / channel. For each submarine link and modulation format, the optimization of launch power and dispersion pre-compensation is analyzed, corresponding to the low-cost margin improvement at the SLTE.

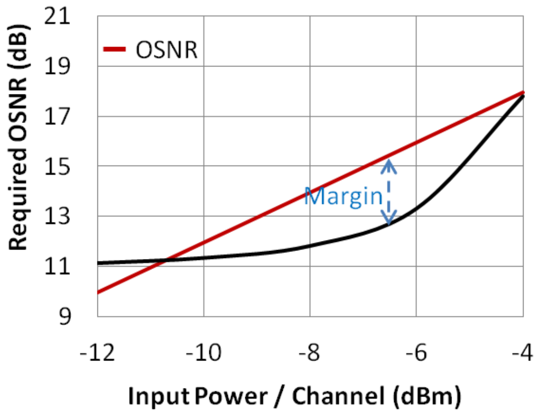

Figure 2: ROSNR as a function of input power / channel for 40 Gb/s CP-QPSK WDM signal with 50 GHz channel spacing at 1550 nm over 6000 km with optimized pre-compensation.

SLTE OPTIMIZATION

An example of the channel power optimization is given in Fig. 2 for 40 Gb/s CP-QPSK WDM signal with 50 GHz of channel spacing over the 6000 km long submarine link. The Fig. 2 shows the maximum system margin of 2.2 dB and the optimum power of -7.5 dBm for the centre channel with the optimum dispersion pre-compensation found previously to be around 500 ps/nm. Similar channel power optimisation is done for the other scenarios and formats. Furthermore, at the optimum channel input power found as shown in Fig. 2, the optimization of the dispersion pre-compensation is achieved over the entire C-band and for analyzed format and submarine links. Together with this low-cost optimization at the SLTE by setting the channel input power and the dispersion pre-compensation, the maximum capacity and reach for the advanced modulation format with the 40 Gb/s and 100 Gb/s bit rate is found.

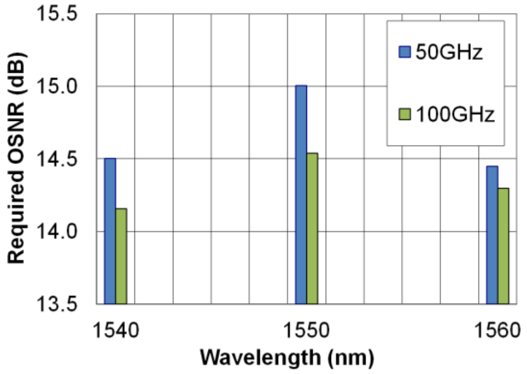

Figure 3: ROSNR as function of the wavelength for 100 Gb/s CP-QPSK WDM signal with 50 and 100 GHz of channel spacing at the optimum pre-compensation and launch power of -5dBm over > 4000 km.

THE MAXIMUM REACH X CAPACITY

In this paper, several submarine distances are checked for each of the bit rate and different channel spacing in a purpose to calculate the maximum reach and capacity transmission. First the 2000 km is analyzed and for each of the bit rate, very good system margin is achieved.

The 40 Gb/s CP-QPSK format shows very good performance over > 4000 km of submarine distances, which is in agreement with the recent field trial provided over similar deployed link [3-4]. The maximum distance with the 40 Gb/s CP-QPSK format is found over 6000 km, as shown in Fig. 2 by simulation analysis. However, the 9000 km submarine distance with 40 Gb/s CP-QPSK shows to give 0 dB margin with the optimized SLTE condition.

The maximum capacity by transmitting the 100 Gb/s CP-QPSK WDM signal with 50 GHz and 100 GHz of channel spacing is successfully transmitted over > 4000 km of submarine link. The results of this analysis achieved at the centre (1550 nm) and two outer channels (1540 and 1560 nm) of the C-band transmission, obtained with the optimum pre-compensation and input power per channel found at -5 dBm, are summarized in Fig. 3. The analysis shows that by the increase of the transmission capacity on double by using 50 instead of 100 GHz of channel spacing, less than 1 dB of the system margin degradation occurred.

SIMPLE RULE FOR OPTIMIZATION

Summary of the dispersion pre-compensation optimization over 4000 km submarine link for CP-QPSK at 100 Gb/s transmission found at the input power per channel over entire C-band is shown in Fig. 4. The results show that the optimum pre-compensations follow the tendency of linear decrease when the wavelength increases. This can be clearly seen by inserting a linear approximation (black line in Fig. 4) over the optimum dispersion pre-compensation points versus wavelength, providing the simple rule for the similar optimizations. An insignificant deviation of the linear dependency of the optimum pre-compensation versus wavelength is also confirmed for some wavelengths by field trial measurements for 100 Gb/s CP-

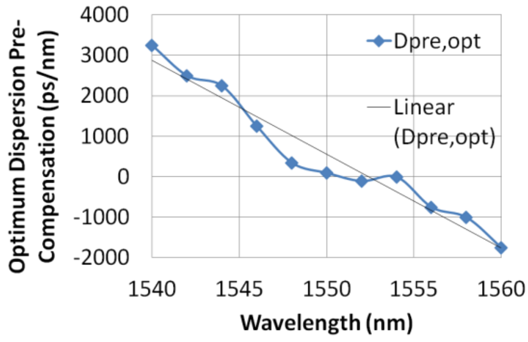

Figure 4: Optimum dispersion pre-compensation as a function of wavelength for 100 Gb/s CP-QPSK WDM signals with 50 GHz of channel spacing at the optimum power of -5 dBm over 4000 km.

QPSK format over similar submarine links in [3-4]. This result and a new rule for the pre-compensation optimization can considerably simplify the time consuming and an exhaustive numerical optimization of the ultra long-haul submarine links with advanced modulation formats for the future capacity upgrades.

4. CONCLUSIONS

In this paper, the low-cost approach of upgrading the submarine links toward higher transmission capacity is shown. With simple optimization of submarine line terminal equipment, by varying the input power per channel and dispersion pre-compensation over the C-band (1540-1560 nm), several submarine distances, based on realistic data were successfully bridged. 40 Gb/s and 100 Gb/s WDM transmission system with 50 and 100 GHz channel spacing and with the CP-QPSK modulation format are analyzed over 2, 4, 6, and 9 thousands km. This work showed that by the increase of the transmission capacity on double by using 50 instead of 100 GHz of channel spacing, less than 1 dB of WDM submarine system performance degradation occurred. The maximum capacity x distance submarine reach of the CP-QPSK format was found. A simple rule for future submarine links upgrades with advanced coherent formats towards 100 Gb/s transmission bit rates is proposed.

ACKNOWLEDGEMENTS

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