Wavelength Conflict Resolution by Spectral Overlap of Two Nyquist-WDM Signals

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Abstract: Two Nyquist-WDM signals are spectrally overlapped to resolve the possible wavelength conflict in network routing. Recovery of individual signals is realized by digital signal processing techniques and has been experimentally demonstrated and characterized.
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1. Introduction

Nyquist signal based wavelength division multiplexing (Nyquist-WDM) is a promising solution to enable the future elastic optical networks (EON), since it occupies minimal bandwidth, which is close to the signal's baud rate, and requires relatively small inter-channel guard band. Hence, it achieves much higher spectral efficiency, compared with traditional optical non-return-to-zero (NRZ) systems. In EON, the frequency range occupied by an optical channel is defined as a frequency slot (FS) [1]. In an EON, traffic blocking may occur when two optical channels from different sources, occupying the same FS, are contending for the same output fiber link. Instead of employing complicated wavelength conversion, optical signal overlap technique is proposed as a low cost alternative solution to resolve this possible wavelength conflict. The intermediate node merely combines the two optical signals, via an optical coupler, after proper signal power control. As the frequency slots are reused, the network throughput is improved. At the receiver, the individual signals can be separated and properly recovered by DSP techniques.

In [2], two optical channels from two different nodes were low-density parity-check (LDPC) encoded at different rates, which enabled the successful de-multiplexing of the two channel signals at one node. In [3], optical physical network coding method was proposed for common channel, in the case of the specific butterfly network topology. Different from the overlapped polarization-multiplexed quaternary phase-shift keying (PM-QPSK) signals in [2] and [3], in this paper, complete spectral overlap of two optical Nyquist PM-QPSK channels is investigated. At the receiver, the decoding DSP technique is based on the conventional PM-QPSK demodulation algorithms. The optical signal with larger power (denoted as S_d hereafter) is decoded first from the spectrally overlapped composite signal (denoted as S_o). After S_d is properly recovered, the other signal (denoted as S_w) can further be recovered via the interference-mitigated signal by subtracting S_d from S_o.

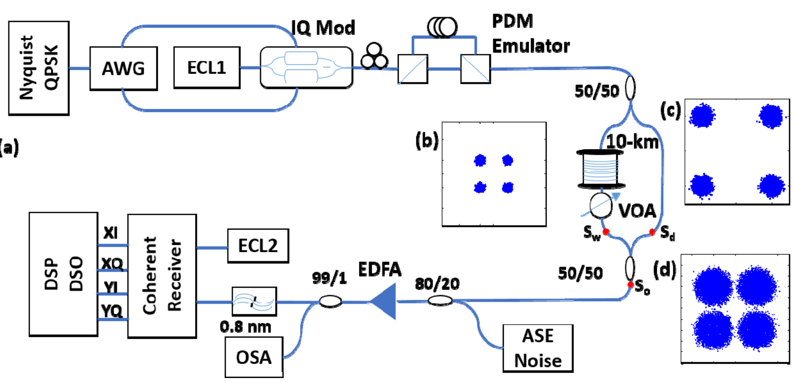

Fig. 1. (a) Experimental setup. The inset shows the phase noise compensated constellations before (b, c) and after (d) optical signal overlap.

2. Experimental demonstration

In Fig. 1(a), an optical Nyquist PM-QPSK signal was generated by driving an optical I/Q modulator with a two-channel arbitrary waveform generator (AWG), followed by a polarization division multiplexing (PDM) emulator. The transmitter laser wavelength was 1550.06 nm. The sampling rate of the AWG was 12 GSa/s and the baud rate of the generated Nyquist signal was 6 GBd with roll-off factor of 0.2. The optical signal was then split into two branches and de-correlated by a piece of 10-km standard single mode fiber (SSMF), forming two optical channels, namely S_d and S_w. Then, their respective signal powers, P_d and P_w, were carefully adjusted by attenuating that of S_w, via a variable optical attenuator (VOA), before being optically combined, via optical coupler, to form the spectrally overlapped composite signal, S_o. We defined the power difference between S_d and S_w as the signal to interference power ratio (SIR). Amplified spontaneous emission (ASE) noise (N_{ASE}) was introduced to control the optical signal to noise ratio (OSNR) of S_o ($OSNR_o = (P_d+P_w)/N_{ASE}$). At the receiver, S_o was acquired by a coherent optical receiver and a four-channel digital storage oscilloscope (DSO). Fig. 1(b) and (c) show the constellations of the two optical channels before being combined, while Fig. 1(d) shows that of the combined composite signal. Note that the constellation in Fig. 1(d) was not similar to that of 16-QAM due to the incoherence between S_d and S_w.

The DSP for the signal recovery involved several stages. First, in order to decode S_d, S_w was treated as the interference. The acquired signal was digitally filtered and re-sampled to 2 samples per symbol. Timing phase recovery based on Gardner timing error detector (TED) was employed. Then, the signal was polarization de-multiplexed and equalized based on the constant modulus algorithm (CMA). The carrier was synchronized by frequency estimate and blind phase search (BPS) method. A two-fold oversampling was preserved throughout the above algorithms. Hence, S_d was retrieved and forward error corrected. To recover the weaker signal S_w, a 2-sample per symbol version of the recovered S_d was reconstructed by Nyquist filtering, and then subtracted from the carrier synchronized signal S_o. As a result, S_w was also recovered, via a second round of the signal processing algorithms.

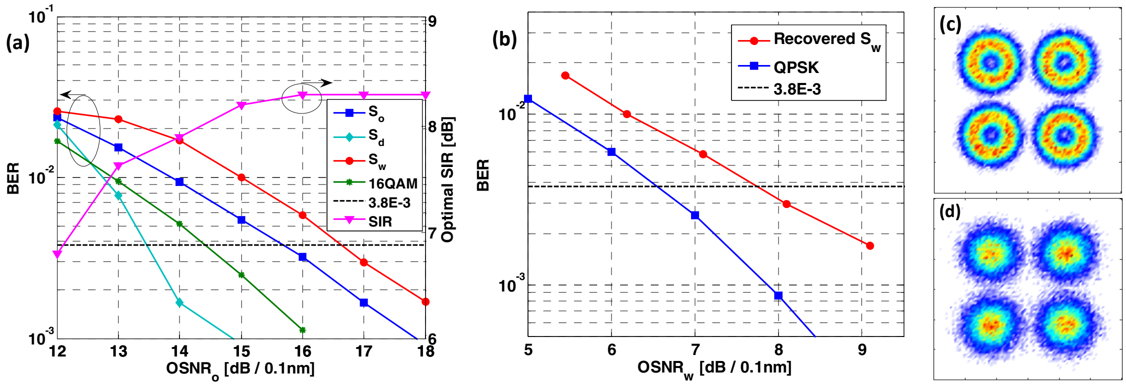

Fig. 2. Experimental results: (a) calculated BER and optimal SIR as functions of $OSNR_o$ for the S_o, S_d and S_w; (b) calculated BER as functions of $OSNR_w$ for cases of recovered S_w and QPSK for transmission; (c) recovered constellations of S_o and S_w with $OSNR_o$ of 16-dB.

Fig. 2 shows the performance of the proposed scheme. The bit error rate (BER) of the spectrally overlapped composite signal S_o, is defined as the average of pre-FEC BERs of the recovered S_d and S_w. At a certain $OSNR_o$ value, BER performance of the overlapped composite signal S_o could be optimized by SIR. Fig. 2(a) shows the calculated BERs for signal S_o, S_d and S_w under optimal SIR with respect to $OSNR_o$. The back-to-back performance of the Nyquist PM-16-QAM is also depicted. For optimal decoding, the required $OSNR_o$ at BER of 3.8×10^{-3} is about 16.8-dB. Compared to that of the 16-QAM case, about 1.3-dB OSNR penalty is observed. It is noted that, a lower BER threshold could lead to a lower OSNR penalty, yet a larger FEC overhead. The optimal SIR varies with respect to the OSNR value, in which the minimal BER of S_o is achieved. Fig. 2(b) depicts the BER of S_w (labeled as "Recovered S_w"), with respect to $OSNR_w$, which is defined as the ratio of the power of S_w to the noise power ($OSNR_w=P_w/N_{ASE}$), and SIR is set to its optimal value. It is compared with the case when only S_w is transmitted (labeled as "QPSK"). The OSNR penalty is about 1.2-dB at the BER of $3.8\times10^{-3,}$ which proves the effectiveness of the recovery and cancellation of S_d. Fig. 2(c) and (d) show the constellations of S_o and S_w after respective carrier synchronizations. It is noted that the constellation of S_o is consisted of four "rings" here. This is the case when the two optical channels, S_d and S_w, are timing and polarization mostly aligned. The results show that two channels S_d and S_w could be successfully demodulated and separated from the overlapped composite signal S_o.

3. Summary

We have experimentally demonstrated the signal recovery of two Nyquist-WDM signals, of which their signal spectra are completely overlapped. This offers the feasibility to combine two optical channels, occupying the same FS, so as to resolve the possible wavelength conflict in network routing. The performance of the proposed scheme, employing 6-GBd Nyquist PM-QPSK signal, has been experimentally characterized. This project was partially supported by a research grant from Hong Kong Research Grants Council (GRF Project No. 14200614).

4. References

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