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Error-free all-optical add-drop multiplexing using HNLf in a NOLM at 160 Gbit/s

E.J.M. Verdurmen, Y. Zhao, E. Tangdiongga, J.P. Turkiewicz, G.D. Khoe and H. de Waardt

The capability of a highly-nonlinear fibre (HNLf) as the phase shifting element in a nonlinear optical loop mirror (NOLM) for all-optical adding/dropping optical time domain multiplexed (OTDM) channels has been demonstrated. Error-free add/drop operation of 40 Gbit/s base rate channels from a 160 Gbit/s OTDM signal has been achieved.

Introduction: An add-drop multiplexer (ADM) is one of the key elements in optical time division multiplexed (OTDM) networks. Various methods of performing OTDM add-drop have been demonstrated. Recently add-drop operation at 16×10 Gbit/s has been demonstrated with the use of a gain transparent ultrafast nonlinear interferometer (GT-UNI) [1] switch and at 4×40 Gbit/s with travelling-wave electroabsorption modulators (TW-EAMs) using an electrical clock input signal [2]. This Letter presents an all-optical add-drop multiplexing method at 4×40 Gbit/s using a commercially available highly-nonlinear fibre (HNLf). The advantage of using HNLf as a nonlinear switching medium is the possibility of realising high speed operation (up to 640 Gbit/s) owing to the ultrafast fibre response time. The advantage of HNLf over conventional dispersion shifted fibre (DSF) is that the length can be significantly shorter and less switching power is required, which in general leads to more robust switching. Several demultiplex experiments with HNLfs have been reported [3, 4]; however simultaneous add/drop operation with HNLfs has not been reported so far.

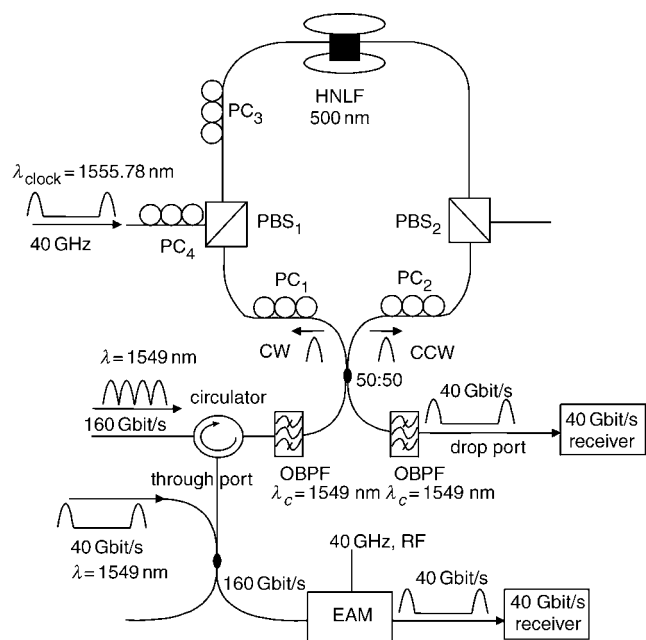


Fig. 1 Experimental setup
OBPF: optical bandpass filter

Experimental setup: The control signal and the 160 Gbit/s OTDM signal are obtained from a modelocked laser (MLL). The MLL produces 39.813 GHz, 1.5 ps full width half maximum (FWHM) pulses at 1549 nm. The 160 Gbit/s OTDM data signal is time multiplexed from a 40 Gbit/s RZ signal generated by modulating the 40 GHz optical clock pulse with $2^7 - 1$ PRBS data with a Ti:LiNbO₃ Mach-Zehnder modulator. To provide a 40 GHz control signal, the wavelength of the optical clock pulse is converted to 1555.78 nm to avoid crosstalk between the control and OTDM signal. The conversion is based on supercontinuum (SC) generation in a 2.25 km DSF. The control signal is acquired by slicing the generated SC spectrum with a multilayer dielectric thin-film filter with 3 dB bandwidth $\Delta\lambda = 0.92$ nm. The generated control pulse width is 6 ps. Fig. 1 shows the setup of the ADM based on the NOLM structure. Both the 3 dB coupler and the 500 m-long HNLf in the NOLM are

non-polarisation maintaining fibre. We use orthogonally polarised signal and control pulse streams in the experiment. The zero-dispersion wavelength of the HNLf is 1545 nm, the dispersion slope is 0.03 ps/km/nm², and the nonlinear coefficient is about $15 \text{ W}^{-1}\text{km}^{-1}$. In the NOLM the 160 Gbit/s OTDM signal is split into two counter-propagating signals. One signal travels clockwise (CW) and the other one travels counter clockwise (CCW) through the loop. The 40 GHz control signal at 1555.78 nm is coupled into the loop through polarisation beam splitter 1 (PBS₁) and travels in CW direction. The walk-off between the signal and control pulse is only 0.95 ps as the HNLf has a very small dispersion slope. The OTDM channel coinciding with the control signal experiences an extra phase shift induced by the cross-phase modulation (XPM) effect. The control signal, which is orthogonally polarised, is removed from the loop through PBS₂, by proper adjustment of polarisation controller 3 (PC₃). Thus, when the CW and CCW signal interfere at the coupler one OTDM channel will be sent to the drop port, whereas the through port contains the three remaining channels. A 40 Gbit/s channel, deduced from the same source as the input signal and controlled by a delay line, is inserted after the through port by a passive fibre combiner. For the remaining 40 Gbit/s channels and the added channel, time domain demultiplexing with a single EAM has been employed to retrieve the 40 Gbit/s tributaries. The switching window is about 7 ps (FWHM) that is slightly wider than the 160 Gbit/s time slot, resulting in a small excess penalty.

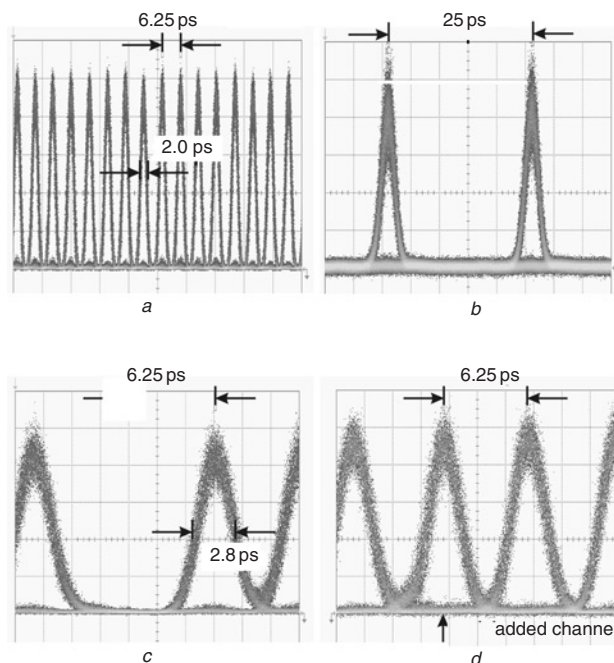


Fig. 2 Eye diagrams

a 160 (4×40) Gbit/s OTDM input signal to the NOLM
b 40 Gbit/s dropped signal at the drop output port of the NOLM
c Empty time slot and the 3×40 Gbit/s through channels
d Through channels with inserted 40 Gbit/s added channel

Results and discussion: In the experiments, the average power of the 160 Gbit/s OTDM input signal coupled into the HNLf is 5 dBm and the average power of the 40 GHz control pulse is 22 dBm. The corresponding control pulse peak power is 660 mW, which induces a π phase shift on one of the OTDM channels that needs to be dropped. Fig. 2 presents the measured eye diagrams at various points of the ADM. Fig. 2a shows the eye diagram of the original 160 Gbit/s OTDM signal. The small signal in the zero level is due to the extinction ratio of the 40 Gbit/s modulator. Figs. 2b and c display the eye diagrams of the dropped channel and through channels, respectively. The eye diagram of the added channel is shown in Fig. 2d. From the eye diagrams we see that excellent dropping and good removal of one channel at the through port are achieved simultaneously. The performance of the OTDM ADM was assessed by measuring BER values. As a reference for the dropped channels we used the 40 Gbit/s RZ signal in a back-to-back BER measurement. Fig. 3 summarises the measured BER performances. Fig. 3a shows

the BER performance of the four dropped channels, and Fig. 3b shows the BER of the through channels and one added channel. The average sensitivity penalty for the dropped channels is 3 dB. As a reference for the through channel we used the original 160 Gbit/s signal as the input signal for the demultiplexer with a single EAM. The average penalty of the dropped through channels is 1.4 dB, and an extra 3 dB penalty for the dropped added-channel. The sensitivity penalties are due to the optical signal-to-noise ratio reduction by ASE noise of the EDFAs in the system and the interferometric crosstalk between the added channel and the remaining signal owing to incomplete removal of the dropped channel at the through port. Also pulse broadening in the through channels is observed from 2 to 2.8 ps, leading to more crosstalk in the demultiplexer with a single EAM because the EAM switching window is too wide and fractional parts of neighbouring pulses are switched to the dropped channel.

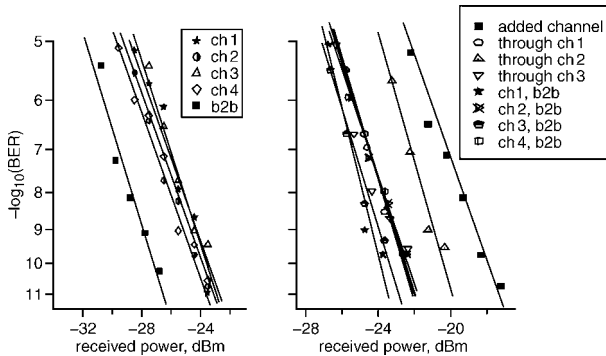


Fig. 3 BER performance
 a Dropped channels
 b Through channels and added channel

Conclusion: We have shown the feasibility of all-optical OTDM add-drop operation at 160 Gbit/s with a 40 Gbit/s base rate, based on XPM in a 500 m-long HNLF placed in a NOLM. Error-free operation

is obtained for all the dropped and through channels as well as the added channel. This principle offers a potential for future OTDM generations reaching far beyond 160 Gbit/s.

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