All-optical TDM add-drop multiplexer based on Time to Wavelength conversion

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Abstract *We demonstrate a novel and highly flexible approach to OTDM add-drop multiplexing based on OTDM-WDM conversion with an intermediary passive spectral filtering stage. Error-free operation at 40 Gbit/s is demonstrated.*

Introduction

All-optical time division add-drop multiplexing (ADM) is likely to prove a key technology within future high-speed optical networks. Previous ADM demonstrations have been based on removal of the individual tributary channels directly within the temporal domain using a synchronised optical /electrical signal at the (lower frequency) tributary data rate, for example Refs.[1,2,3]. Whilst good performance can be achieved, adapting the basic approach to allow more complex processing at the nodes (e.g. dropping of multiple channels, bit-interchange etc.) is however challenging and invariably leads to complex system designs.

In this paper we propose an alternative ADM approach (see Fig.1) in which, rather than perform the processing directly within the time domain, we convert the OTDM signal onto a WDM replica, which maps the individual tributary channels onto discrete separate wavelengths, and process it within the frequency domain using passive optical filtering elements. Since it is possible to create relatively complex filters with well defined phase and amplitude response, e.g. using fiber Bragg grating technology, this provides a very compact and efficient way to simultaneously process the individual tributary channels. After filtering the signal is re-converted back into an OTDM signal for onward transmission.

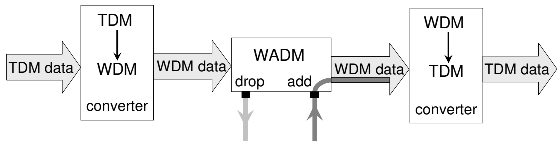

Fig. 1. Operation principle of the time division add-drop multiplexer. (WADM: Wavelength add-drop multiplexer)

Herein we show the principle and viability of the general approach by demonstrating the error free adding and dropping of 10 Gbit/s channels from a 40 Gbit/s OTDM signal. This function requires only a relatively straightforward intermediary filtering stage based on a grating-based wavelength add-drop multiplexer (WADM). However, it is to be appreciated that incorporating further filtering elements within the set up to allow more complex processing should be a relatively straightforward extension of this work. The key issue in this approach is how best to perform the OTDM-to-WDM and WDM-to-OTDM format conversion stages. In these experiments we do this through the all-optical switching of synchronised chirped square pulses and cw beams respectively in nonlinear optical loop mirrors fabricated from highly nonlinear fibres (HNLFs).

Experiment and Results

Our experimental setup is shown in Fig.2. The OTDM data pulses had a FWHM of 6 ps, central wavelength at 1547 nm and a 3dB bandwidth of 0.5 nm. They

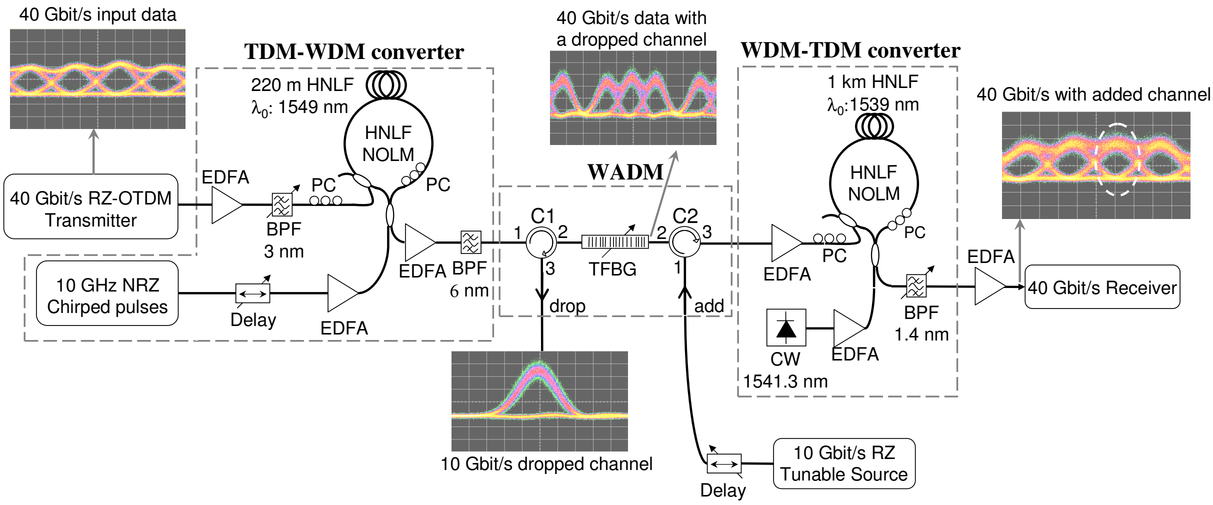

Fig. 2. Experimental setup and eye diagrams for OTDM add-drop multiplexing of a 40 Gbit/s signal. (HNLF: highly nonlinear fiber, PC: polarisation controller, BPF: band-pass filter, TFBG: tunable fiber Bragg grating)

were modulated externally with a pseudo-random data sequence of 2^{31}-1 length and then passively multiplexed to a line-rate of 40 Gbit/s. Fig.3(a) shows the corresponding spectrum. At the add-drop multiplexer input the 40 Gbit/s data was amplified to an average power of 20 dBm and launched into the control port of a highly-nonlinear fiber optical loop mirror (HNLF NOLM), (disp. slope=+0.029 ps/nm^2/km, λ_0=1548 nm, γ=18 $W^{-1}km^{-1}$ and a length of 220 m). The signal to the HNLF NOLM, comprised ~100 ps linearly chirped rectangular pulses at a 10 GHz repetition rate, details of their generation are given in Ref.[4]. The large amount of chirp and the rectangular shape of these pulses results in a 6 nm wide, highly flat spectrum, as shown in Fig. 3(b). At the HNLF NOLM output a WDM replica of the original data was carved onto the chirped pulses, Fig. 3(c). The control signal was then filtered out using a 6 nm band-pass filter centered at 1551.5 nm, which is the central wavelength of the chirped pulses. Each channel bandwidth was 0.68 nm and the spacing between them 1.4 nm. The switched signal was then transmitted through a tunable fiber Bragg grating (FBG) [5], with a transmission loss of 15 dB within the 1.2 nm bandgap. (Note that this figure by no means represents the limits of FBG technology). The circulator arrangement shown in Fig.2, allows dropping of the channel reflected off the FBG through port 3 of C1 and the addition of a new 10 Gbit/s channel through port 1 of C2. Fig. 3(d) shows the spectrum at port 2 of C2 after the third channel has been reflected off the FBG. Fig. 3(e) shows the spectrum at port 3 of C2 after a new channel has been added. Replacing C2 with a 3dB coupler would enable a different wavelength to be used as the add-

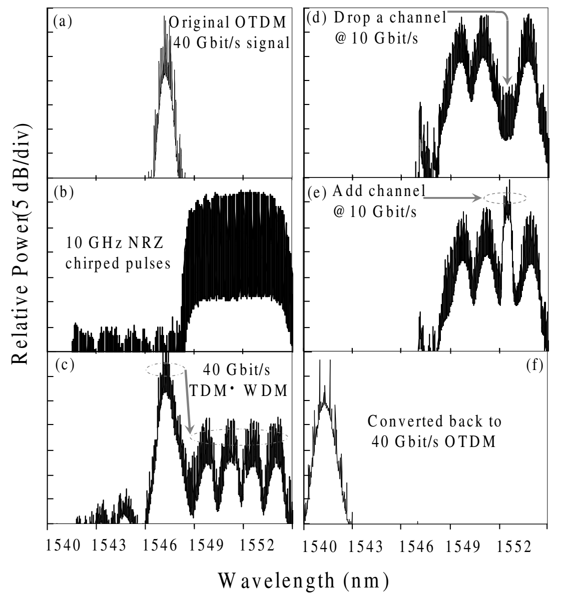

Fig. 3. Spectra at different stages of the OTDM add-drop multiplexer. (a) Original 40 Gbit/s signal, (b) chirped pulses, (c) chirped WDM replica, (d) channel drop, (e) Channel add, (e) final 40 Gbit/s OTDM signal.

channel. The new data pulses (FWHM = 9 ps) were generated by externally modulating a tunable continuous-wave laser. The final format conversion stage used a second HNLF NOLM (dispersion slope=+0.03 ps/nm^2/km, λ_0=1539 nm, γ=18 $W^{-1}km^{-1}$ and a length of 1 km) to convert the multi-wavelength signal back onto a single wavelength. The WDM signal (amplified to an average power of 15 dBm) was used as the NOLM control to switch a continuous-wave beam at 1541.3 nm. At the output of the NOLM a 1.4 nm band-pass filter isolated the switched signal from the control, as shown in Fig. 3(f). The final resulting signal was diagnosed using a 40 Gbit/s

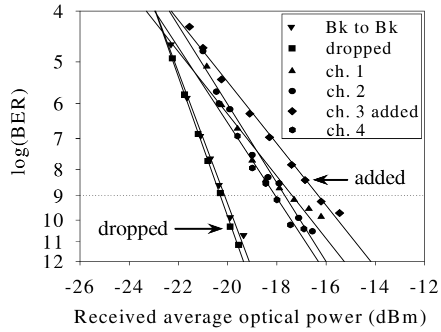

Fig. 4. Bit error rate performance of add, drop and adjacent channels with respect to back to back.

receiver consisting of a 40:10 Gbit/s electro-absorption modulator based demultiplexer. Fig. 4 shows the bit error rate (BER) performance for each of the demultiplexed channels including the new added channel with respect to the ADM back to back. Here the added channel was at 1546nm which negated the effects of the relatively poor extinction ratio of the FBG used. Error-free operation was achieved with a power penalty between 2 and 4 dB. No degradation was observed on the dropped channel.

Conclusions

We have demonstrated a flexible new approach for the processing of OTDM signal that combines time to wavelength domain conversion (and vice versa) with intermediary spectral filtering. Using this approach we demonstrate an OTDM add-drop function and obtain error free operation at 40Gbit/s using a fiber based implementation. We consider our results to highlight the strength and flexibility of this format conversion approach which should readily allow for more advanced functionality without great increase in overall system complexity.

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