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160 Gbit/s OTDM add-drop networking using 275 km installed fibres

E. Tangdiongga, J.P. Turkiewicz, H. Rohde, W. Schairer, G. Lehmann, E.S.R. Sikora, Y.R. Zhou, A. Lord, D. Payne, G.D. Khoe and H. de Waardt

A field-installed 160 Gbit/s OTDM network comprising an OTDM add-drop node placed between two existing fibre links is demonstrated. An excellent performance of signal transmission, subharmonic clock recovery, and add-drop function is reported.

Introduction: 160 Gbit/s optical time domain multiplexing (OTDM) technology is only interesting if full add-drop functionality can be realised on the existing fibre infrastructure [1]. A 160 Gbit/s OTDM add-drop node based on the gain transparent ultrafast nonlinear interferometer (GT-UNI) has been demonstrated under laboratory conditions [2]. In this Letter we present a 160 Gbit/s OTDM network built using legacy fibres. The network comprises a 160 Gbit/s transmitter, a 160 Gbit/s add-drop node placed between two field installed fibre links connecting the British Telecom telephone exchanges of Ipswich and Newmarket, and a 160 Gbit/s receiver node. We achieved a high performance operation of all OTDM network functionalities: transmission, clock recovery (CR), and switching on field experimental condition.

Experimental setup: Fig. 1 presents the OTDM network setup. The network consists of the following elements: a transmitter, a first fibre link, an add-drop node equipped with a CR circuit, a second fibre link, and a demultiplexer node with another CR circuit. Each of the fibre links consisted of two spans of 68.85 km legacy standard singlemode fibre (SSMF). The SSMF links, which have been used for commercial purposes for more than five years, are largely located alongside traffic roads. The average loss, dispersion and differential group delay of fibre spans are, respectively, 16.3 dB, 16.83 ps/nm/km, and 0.61 ps.

Fig. 1 OTDM network setup

The transmitter, the add-drop node, and the receiver node were sited in Ipswich. Er-doped fibre amplifiers (EDFAs) and dispersion compensation modules (DCMs) were installed in Newmarket and Ipswich. The equipment was placed in a standard exchange room without climate controls, which, given the large amount of equipment used in the evaluation, gave rise to a temperature variation of more than 10°C.

A 160 Gbit/s data signal at a wavelength of 1551.7 nm was generated by passively multiplying 2 ps FWHM pulses (9.95328 GHz rep. rate) from an erbium-glass oscillator pulse generating laser. The pulses were modulated in an amplitude modulator with a pseudorandom bit sequence (PRBS) of length 2^7-1 . After being amplified by an EDFA the data signal entered the first transmission span to Newmarket. Fibre dispersion and optical loss in 68.85 km SSMF was compensated at Newmarket using a two-stage EDFA with a DCM before coming back to Ipswich in the second span. Degradation due to polarisation mode dispersion was mitigated by coupling the data signal into one principal state of polarisation of each transmission section. Before the add-drop node, the residual dispersion was finely tuned by additional DCMs. The 160 Gbit/s OTDM add-drop node consisted of the following parts: a 160 Gbit/s GT-UNI based add/drop multiplexer, a subharmonic 10 GHz CR circuit based on a single unidirectional EAM, and a 10 Gbit/s fibre ring laser based return-to-zero data source supplying the add channel. The CR circuit has an RMS time jitter less than 210 fs, a wavelength range over 10 nm, an input dynamic range more than 10 dB, and a locking range around 10 MHz. These excellent properties hold for longer data pattern lengths. The wavelength, amplitude, and polarisation of the add channel was adjusted to meet the transmitted signal in the through port. After the add-drop node the data signal consisted of 15×10 Gbit/s through channels plus an added channel transmitted over the second section of fibre. In the 160 Gbit/s OTDM receiver node, all-optical demultiplexing based on four-wave mixing (FWM) in a semiconductor optical amplifier (SOA) was utilised to retrieve the 10 Gbit/s tributaries. Another CR circuit, which is similar to the one attached to the add-drop node, was used to synchronise the demultiplexer to the incoming data.

Results and discussion: Fig. 2 presents eye diagrams captured using an optical sampling oscilloscope in the various points of the link. The eye pattern is open for all channels of the signal. Excellent transmission and switching is clearly visible. The GT-UNI switching window was 4 ps for the drop and 6 ps for the through function. The performance of the OTDM network was determined by measuring bit error rate (BER) values. Fig. 3 presents the BER values against the average power to the 10 Gbit/s preamplified receiver. Fig. 3a shows the BER performance of the GT-UNI when it drops one of the 16 channels for a back-to-back (b2b) scheme, 137 and 275 km transmission. Also, we depicted the BER performance of the 10 Gbit/s receiver as the reference. The multiplexer stage and the GT-UNI introduced a 6 dB sensitivity penalty compared to the reference BER curve. This penalty increases by 1 dB for 137 km and 2 dB for 275 km. Next, we fixed the GT-UNI switch after the first link and examined its through/add output using the FWM-SOA demultiplexer. The BER performance of one of the 15 through channels is shown in Fig. 3b. We observed a sensitivity difference of approximately 8 dB when compared to the GT-UNI drop performance. This large difference is primarily caused by the low FWM efficiency, causing a relatively poor optical signal-to-noise ratio value of the demultiplexed 10 Gbit/s signal. The main result in Fig. 3b is that the GT-UNI switch introduced sensitivity penalties of around 2 dB only. These small penalties are largely caused by large attenuation of the 1.5 μ m data signal by the 1.3 μ m gain transparent SOA. Fig. 3c shows the BER performance of a 10 Gbit/s add channel that was inserted in the empty time slot of the through signals (Fig. 2d). Two BER curves are shown. One curve was obtained at the GT-UNI through output and the other at the receiver node. The add channel performance shows a straight line with a BER = 10^{-9} sensitivity of -22.5 dBm, indicating an excellent simultaneous drop-insert operation of the switch. The through channels in direct vicinity of the drop channel showed 3-4 dB penalties higher than the other channels. After travelling the additional two spans, the quality of the add signal is degraded by approximately 4 dB. Penalties of the through channels increased rapidly and were difficult to keep constant; however, they were significantly above the forward error correction threshold for BER < 10^{-12} . This rapid degradation is caused by the fact that the operational margins are very tight for this transmission range. Moreover, the time varying effects like high-order PMD started to become detrimental to the signal quality. Those margins can be relaxed by applying an advanced dispersion and PMD compensation method and Raman amplification.

Fig. 2 Eye diagrams

- a 16 × 10 Gbit/s OTDM input signal to link
 b 10 Gbit/s drop signal at 137 km
 c 15 × 10 Gbit/s through signals at 137 km
 d 15 × 10 Gbit/s through signals with inserted 10 Gbit/s add signal at 275 km

Fig. 3 BER performance

- a Drop signal evaluated with GT-UNI
 b Through signal evaluated with FWM-SOA
 c Add signal evaluated with FWM-SOA

Conclusions: A fully functional 160 Gbit/s OTDM add-drop network has been demonstrated for the first time. The network was built based on the legacy SSMF fibre. All network functionalities: transmission, clock recovery, and switching, show excellent performance. Further enhancement of the network performance requires application of the automatic dispersion and PMD control, and Raman amplification. This result is evidence that OTDM add-drop functions are feasible in the existing fibre links.

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E. Tangdiongga, J.P. Turkiewicz, G.D. Khoe and H. de Waardt
 (COBRA Research Institute, Eindhoven University of Technology,
 EH-12, PO Box 513, Eindhoven, MB NL-5600, The Netherlands)

E-mail: e.tangdiongga@tue.nl

H. Rohde, W. Schairer and G. Lehmann (Siemens Corporate Technol-
 ogy, Otto-Hahn-Ring 6, Munich DE-81730, Germany)

E.S.R. Sikora, Y.R. Zhou, A. Lord and D. Payne (BT, Adastral Park,
 Martlesham Heath, Ipswich IP5 3RE, United Kingdom)

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