Field Trial of WDM-OTDM Transmultiplexing employing Photonic Switch Fabric-based Buffer-less Bit-interleaved Data Grooming and All-Optical Regeneration

G. Zarris[1], F. Parmigiani[2], E. Hugues-Salas[1], R. Weerasuriya[3], D. Hillerkuss[4], N. Amaya Gonzalez[1], M. Spyropoulou[5], P. Vorreau[4], R. Morais[6], S.K. Ibrahim[3], D. Klonidis[5], P. Petropoulos[2], A.D. Ellis[3], P. Monteiro[6], A. Tzanakaki[5], D. Richardson[2], I. Tomkos[5], R. Bonk[4], W. Freude[4], J. Leuthold[4], and D. Simeonidou[1]

1 – Photonic Networks Laboratory, University of Essex, Colchester CO4 3SQ, U.K., Email: gzarris@essex.ac.uk
2 – Optoelectronics Research Centre, University of Southampton, U.K., 3 – Photonic Systems Group, Department of Physics and Tyndall National Institute, University College Cork, Ireland, 4 – Institute of Photonics and Quantum Electronics, University of Karlsruhe, 76131 Karlsruhe, Germany 5 – Athens Information Technology Centre, Athens, Greece, 6 – Nokia Siemens Networks Portugal S.A., 2720 Amadora, Portugal

Abstract: We report, for the first time, a field trial of a novel 42.7Gbps/128.1Gbps WDM/OTDM grooming node, and confirm node interoperability and the data integrity of asynchronous retiming.

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1. Introduction

The rapid growth in network traffic rates will increase the significance of data grooming for two reasons: First, its share in the overall network resources is set to increase; and secondly, current, predominantly electronic, methods of traffic grooming make for one of the least scalable aspects of today's technology in terms of cost and power consumption [1]. As a result, innovative solutions to address data grooming are being sought [2], based on a host of optical and electronic technologies, and different paradigms of multi-granularity. In future high capacity networks a coarse granularity of 100's Gb/s may be desirable. In this context, optical time division multiplexing (OTDM) may find increasing relevance. Nevertheless, to realise the potential benefits of OTDM in a multi-granular network, techniques and technologies for the efficient access and switching of tributaries need to be developed.

In this paper we present, for the first time, the results of two field experiments involving a WDM-OTDM grooming switch capable of providing time-slot, wavelength, and space switching [3]. The technologies used are highly scalable in terms of bit-rates and offer the potential of very low power consumption. The switch could be applicable to edge/core and core traffic grooming in the future network.

2. Optical grooming switch architecture

Fig. 1a depicts the grooming switch architecture [3], which interconnects up to three 43 Gb/s channels – selected using MEMS switch from lower bit-rate WDM domains – with an OTDM domain which carries 129 Gb/s (3x43G) bit-interleaved OTDM channels. It consists of three main building blocks, namely, WDM-OTDM with time-slot interchange (TSI), OTDM-WDM demultiplexing, and all-optical 2R regeneration. All 43 Gb/s channels, whether originating in the OTDM domain or the WDM domain, are input in a MEMS space switch, which provides non-blocking circuit connectivity. In more detail, first, the WDM-OTDM consists of three dual-gate asynchronous digital optical regenerator (ADORE) units [4], each mapping one 43Gb/s on/off keying (OOK) channel on one OTDM time-slot. TSI can be performed by altering the mapping of WDM channels onto ADORE units.

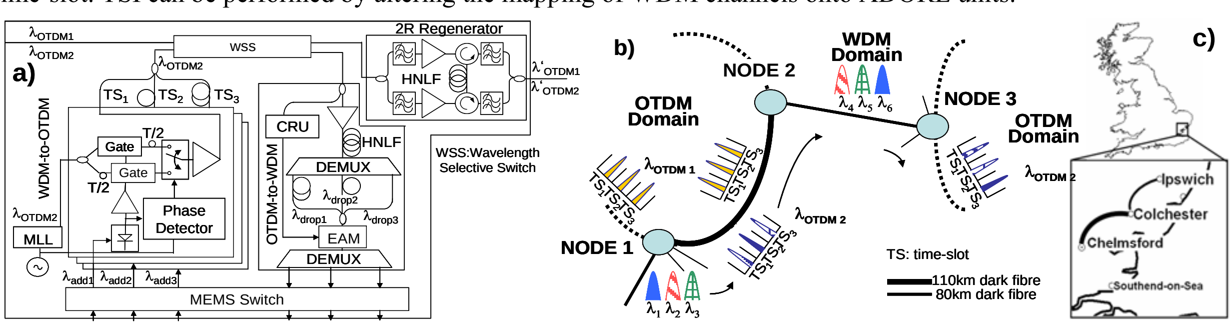

Fig. 1a. Grooming switch architecture [3]; 1b. Network scenario; 1c. Dark fibre network

The ADORE provides regeneration, retiming, pulse width adaptation and wavelength conversion onto a local mode-locked laser (MLL). The retiming action, in particular, concerns the translation of the input signal frequency to a node-specific frequency determined by the node internal clock. In this way, and without the need for electronic buffers, all WDM tributaries end up with precisely the same clock frequency, which is necessary for bit-interleaving tributaries to form an OTDM channel. Retiming action, nevertheless, means that bit-slot slippages take place. It is therefore necessary to provide a mechanism for maintaining data integrity in grooming (see section 3). Second, OTDM-WDM is achieved by wavelength conversion using offset filtering of self-phase modulation (SPM) broadened spectrum in highly non-linear fibre (HNLF), followed by a single electro-absorption modulator (EAM) based optical gate [5]. A clock recovery unit (CRU) [6] is used here to provide the EAM with a synchronous clock signal. Third, the 2R regenerator is also based on offset filtering of SPM broadened spectrum in HNLF, and can simultaneously process two 129 Gbit/s wavelengths, if bidirectional architecture is considered [7].

3. Field experiments and results

The field trial was performed using two dispersion compensated SMF-28™ dark fibre sections (Fig. 1c). The first section, Colchester-Ipswich, was 100% pre compensated using slope matched dispersion compensating module and had a round trip length of 80 km and represented an access link transmitting 42.7 Gb/s channels. The second, Colchester-Chelmsford represented a link in the core network, had a round trip length of 110 km and was 80% pre compensated and 20% post compensated and carried 129 Gb/s channels.

Two experiments were performed with the aim of demonstrating key network functions in the following scenario (Fig. 1b). Node 1 performs WDM-OTDM grooming of traffic which originates in an edge 43 Gb/s WDM domain. In Node 2 a single 2R regenerator regenerates two 129 Gb/s channels. The originally groomed OTDM channel is subsequently OTDM-WDM demultiplexed. Node 3 retimes one of these WDM tributaries and, together with other two local 43 Gb/s channels, it forms a new OTDM channel which is launched in the second OTDM domain. The above network scenario is demonstrated in two separate experiments, with the first experiment demonstrating the interoperability of Nodes 1 & 2, and the second the interoperability of Nodes 2 & 3.

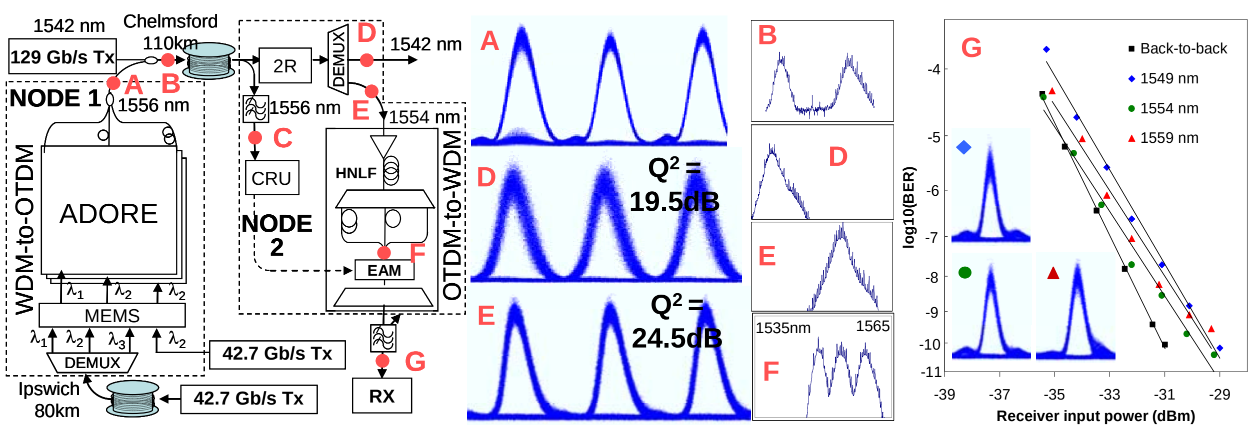

Fig. 2. Experiment 1 setup and results – OTDM grooming, transmission, and tributary separation.

In the first experiment (Fig. 2), 3x43Gb/s 33% RZ OOK channels at wavelengths λ_1=1547.7nm, λ_2=1549.3nm and λ_3=1550.9nm were transmitted in Ipswich link. The data pattern consisted of a repeating 2^7-1 pseudo random bit sequence (PRBS) of 1ms duration, and a single modified 2^{19}-1 PRBS serving as a 1µs guard-band with mark ratio 52.5%. Of the three transmitted channels, λ_1 subsequently entered an ADORE unit, which was configured as in [4,8], including a 15dB gain pre-amplifier with no optical band-pass filter. The ADORE detected the guard-band by simple power measurement, and a control circuit allowed selection of the correct phase for each 1ms burst (i.e. allowing for bit-slot slippages) with a 440ns switching time. In this way, data block integrity was assured during natural variations of input data phase in the dark fibre. For certain tests we used a computer controlled tunable delay at the ADORE input to accelerate the relative variation of input phase up to 9ps per second max. The left eye in inset A, Fig. 2 shows the ADORE output eye over a controlled 1 bit (i.e. 23ps) sweep, at step size of 0.1ps, of the input phase. During such controlled phase sweeps we recorded, in an error detector (ED) gated at the edges of the guard-band, error free operation (zero errors) down to -27dBm RX power, suggesting an approximate penalty of 3-4dB due to eye closure, which is in agreement with previous stand-alone testing [8]. Two local channels at λ_2 were pulse-width adapted, wavelength converted onto the same MLL, and interleaved together with the ADORE output to form the OTDM channel at 1556nm (inset A, Fig. 2). A second 129 Gb/s OTDM channel at 1542nm was generated using a semiconductor-based MLL and was transiting the node. After transmission, both OTDM channels were 2R regenerated [7], applying 2nm blue-offset filtering. The 1542nm channel was restored to its pre-transmission quality, according to Q^2 and BER measurements. The regenerated 1556nm was exhibiting an open eye of Q^2 24.5dB, irrespectively of the input data phase to the ADORE. This was subsequently OTDM-WDM demultiplexed into wavelengths 1549, 1554 and 1559nm, and burst mode BER measurements are shown in Fig. 2, along with the back-to-back EAM-demultiplexed 1556nm OTDM channel. The maximum penalty is 2dB. The degradation was mainly due to the presence of a small leading pulse from the MLL source that was spreading during transmission into adjacent pulses causing beating, thus affecting CRU performance.

In the second experiment (Fig. 3), an improved MLL source was used, along with improved filtering in the OTDM-WDM sub-system. A 129Gb/s OTDM at 1556 nm was formed by interleaving three 43 Gb/s tributaries of the same data pattern (incl. guard-bands) as in the first experiment. The OTDM channel was launched in the Chelmsford link and was subsequently 2R regenerated with 2nm blue-offset filtering. The regenerated signal was then OTDM-WDM demultiplexed to wavelengths λ_4=1549, λ_5=1554, and λ_6=1559 nm. All three demuxed channels were transmitted in the Ipswich link. At this point, BER measurements show no penalty on the 1554 and 1559nm tributaries, compared with the back-to-back EAM-demuxed 1556 nm channel. However, the 1549nm shows a small, 0.5dB penalty, and an error floor (below 10^{-12}). This is due to insufficient broadening in the OTDM-WDM HNLF in the shorter wavelength side. Next, the 1559nm channel was input to one ADORE. The ADORE output eye was confirmed to be error free (zero errors) for a whole 1 bit period (23ps) sweep of the input data phase. Along with two other tributaries generated from two local 42.7 Gb/s 33% RZ channels, this tributary was then groomed on a 129 Gb/s OTDM channel at 1556nm. Once again, the eye diagram confirms that the 2R regenerator is capable of restoring the ADORE eye for transmission into the new OTDM domain.

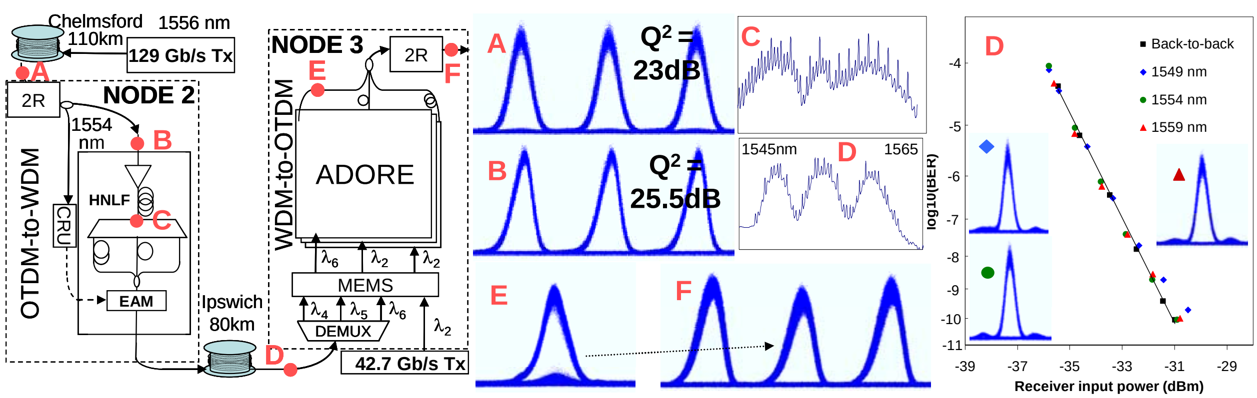

Fig. 3 Experiment 2 setup and results – OTDM transmission, tributary separation, WDM bridge and re-aggregation

4. Conclusions

Our results confirm, first, the data integrity of the asynchronous retiming scheme in both cases of edge traffic grooming and OTDM domain interconnection and, second, the potential of the all-optical techniques used for signal regeneration and wavelength conversion in small scale OTDM domains. The great potential of the asynchronous retiming scheme in transparently interconnecting OTDM domains will be discussed at the conference.

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