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SEVENTH FRAMEWORK PROGRAMME

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FLEXIBLE OPTICAL CROSS-CONNECT NODES

ENABLING NEXT-GENERATION FLEXIBLE OPTICAL NETWORKING

SPECIFIC TARGETED RESEARCH PROJECT (STREP)

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Report on the design and implementation of elements for the 'add' function of the node

Lead beneficiary: Aston Institute of Photonic Technologies

Contact person: Simon Fabbri

Address: Aston University, Aston Triangle, B4 7ET, Birmingham, UK

Email: s.fabbri@aston.ac.uk, Tel.: +44 121 204 3512

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Contributing institutes: Aston Institute of Photonic Technologies

Authors: Simon Fabbri, Stylianos Sygletos, Andrew Ellis

This report has for goal to present the progression of the studies undertaken as part as the work package 4. It is oriented toward the development of a prototype of flexible node for future network, with the implementation of the 'add' and 'drop' functions required. This document reports the experimental node demonstration with the use of an All-Optical Orthogonal Frequency Division Multiplexing (AO-OFDM) system. A single channel was drop and a new channel was added to the AO-OFDM superchannel. The node architecture presented here allows for future optical nodes capable of routing terabit/s signals.

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The optimum utilization of the legacy optical fibre infrastructure can only be achieved in the future through the use of fully flexible superchannels, filling the entire transmission window. While leading research groups are approaching the fundamental limit of standard fibre in point-to-point systems, optical networks require the use of Reconfigurable Optical Add/Drop Multiplexers (ROADMs). The combination of superchannels and ROADM nodes has recently attracted attention as the way forward to respond to the ever growing need for communication

1.1 Context

Future network hubs will undertake the manipulation of very closely aggregated channels using OFDM, Nyquist WDM or even overlapping channels with All-Optical OFDM (AO-OFDM). The use of high performance optical filters can reduce the guardband required between optical channels while maintaining a high quality signal(2). However the guardband remains finite. Interferometric solutions have been proposed with the advantage of dropping the channel of interest from the superchannel with no impact on the adjacent channels(3). The drop channel is extracted from an optical copy of the main signal then added back to the unaffected superchannel with a phase shift, to interferometrically remove it. This approach offers the possibility to implement ROADMs with zero-guardband and overlapping signals alike, and relax the filters requirements. A recent implementation has been demonstrated emulating an interferometer composed of an electrical path and an optical path requiring the use of a full coherent receiver and high speed transmitter. The interferometer was completed with a complex Four Wave Mixing process to insert the new data(1).

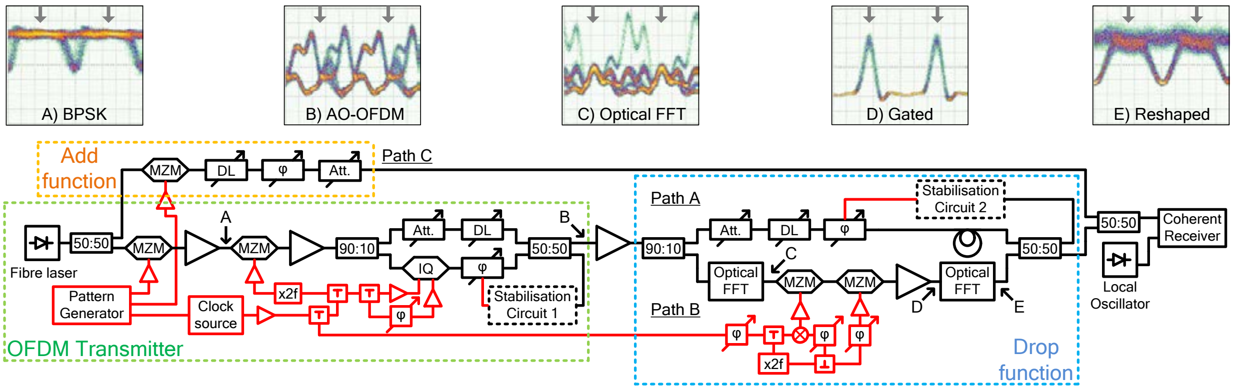

Fig. 1: Top: Intensity eye diagrams at various points, arrows representing the center of the eye.

Bottom: Experimental setup of the AO-OFDM transmitter (left, green) and of the proposed all optical node with drop function (right, blue) and add function (top, orange). Polarisation controllers not pictured for clarity.

MZM: Mach-Zehnder modulator, DL: tunable delay line, φ: tunable phase shifter, Att.: tunable attenuator, IQ: dual parallel MZM

1.2 Node Scheme

We present the Terabit Interferometric Drop, Add and Extract (TIDE) scheme. The purely fibre based node was demonstrated using AO-OFDM. The signal entering the TIDE node is split into one through-path A and a second drop-path B. The second path consists of an AO-OFDM demultiplexer based on optical FFT(4) followed by an optical sampling gating. The optical samples are reshaped to resemble a single channel using a second optical FFT. When the two paths are recombined the channel to be dropped is interferometrically suppressed. The vacant part of the spectrum is then filled with the add channel from path C. Given that the TIDE node is all-optical, the node is not affected by the bandwidth of the superchannel manipulated and thus it is compatible with future terabit/s flexible optical transport networks.

The figure 1 presents a schematic of the experimental implementation of the flexible all-optical node proposed. This report focuses its content on the Add function and the Drop function part of Fig. 1 since it is the core of the node. The transmitter on the left is an experimental emulation of a realistic AO-OFDM superchannel. It provides ten channels, each of which being modulated with 10 Gb/s BSPK.

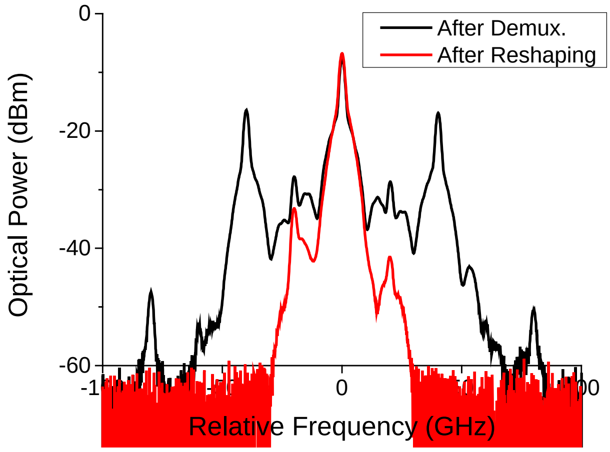

Fig. 2: Spectrum of the channel to be dropped after demultiplexing (black), and after reshaping (red)

The Drop function is obtained by interferometrically suppressing the channel to be drop from the AO-OFDM. It is thus composed of two arms named path A and path B. The first arm is a through path, it is constituted of solely of power control, delay line, and of the phase control required to obtain the phase difference needed for the channel suppression. The path B is more complex since a full channel extraction and reshaping is performed. The arm is implemented as follow: demultiplexing of the channel to be suppressed using optical FFT filter; optical gating to remove crosstalk leaking due to imperfect filtering and imperfect transmitter; and reshaping the pulse train into a cleaned channel using a second optical FFT filter.

The demultiplexer filter was formed of two Delay Line Interferometer (DLI) of Free Spectral Range (FSR) of 20 GHz and 40 GHz respectively followed by a narrow 0.4 nm optical filter. Figure 2 presents the spectrum of the demultiplexed channel to be dropped. Since the filter implemented was the equivalent to a second order optical FFT, residual channels can be observed. However as the eyediagram labelled c) of the Fig.1 shows, a clear sampling point is present free of crosstalk. The optical gating allows selecting the clean part of the time period and hence extracting the data pattern phase encoded of the channel to be dropped.

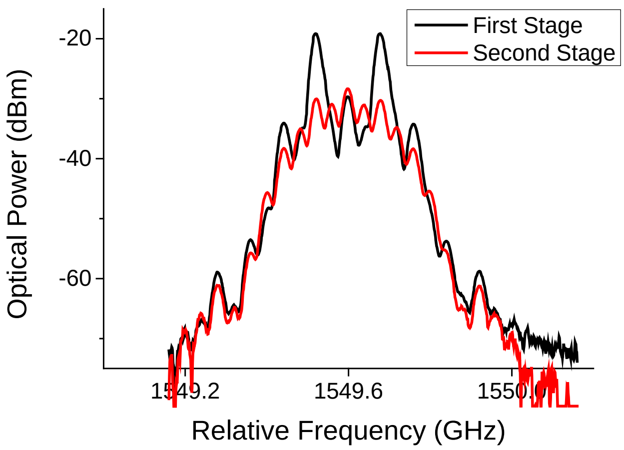

Fig. 3: Spectrum of the optical gating after the first MZM (left), and after the second MZM (right)

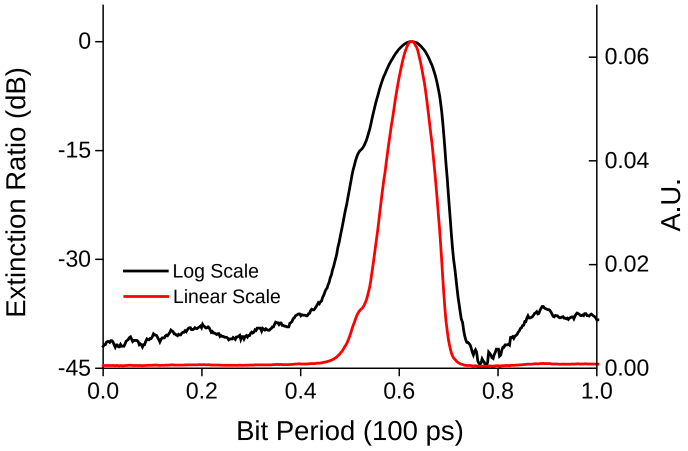

Fig. 4: Pulse obtained from the optical gating cascaded MZMs structure in logarithmic and linear scale

The optical gating was performed using two cascaded MZMs. The first device is driven by a strong 20 GHz RF signal extrapolated from the 10 GHz system clock source. The modulator is biased to produce a narrow pulse train characterized with a repetition rate of 20 GHz. The following MZM will suppress every second pulse providing a pulse stream at the AO-OFDM symbol period. This is done by driving the second modulator at 10 GHz and using an RF phase shifter to perform temporal alignment of the corresponding switching window. Hence, the 20 GHz pulse train coincides with a null and a peak of the slower period pulse train. In addition, to maintain a high extinction ratio and to suppress the unwanted crosstalk, 30 GHz component is added for driving the second modulator. The spectrum of the channel at different point of the optical gating is presented in figure 3.

The pulse obtained by optically gating a CW source had a FWHM of 11.6 ps and an extinction ratio >35 dB. Fig. 4 shows the pulse shape obtained with CW and the optical gating of the channel of interest is shown in Fig. 1 with the subplot d). A high purity pulse train is obtained; the wider pulse is due to the limiting bandwidth of the sampling scope used.

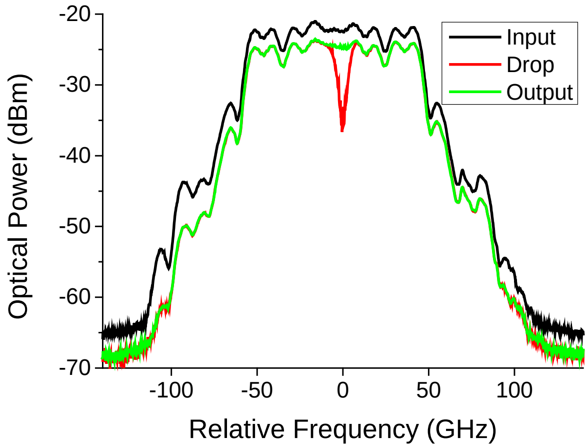

Fig. 5: Optical spectrum at the input, after the center channel drop and after the addition of a new channel

The transform from pulse train to cleaned channel is obtained through the use of a second optical FFT. Due to experimental limitation, the filter was constituted of one DLI of 20 GHz FSR, followed by a 15 GHz Gaussian filter programmed in a WSS. The reshaped channel eyediagram is presented in Fig.1 by E). Performance measurement of the channel to be dropped after the demultiplexing and after the reshaping using a coherent receiver gave a Q-factor improvement of 4 dB due to the reshaping. While Q-factor of 20 dB was obtained, when compared to original single channel, the few dB penalty was attributed to perfectible reshaping filter. Indeed, the eyediagram E) clearly shows a broadening of the

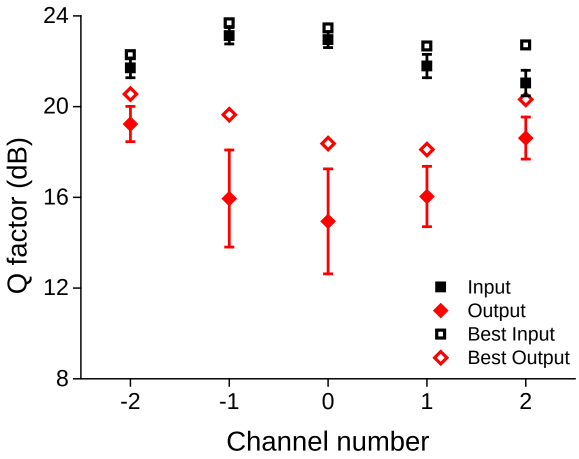

Fig. 6: Q factor measurement for the five central channels: Input (square) and Output after drop and addition (circle).

transition duration due to some over filtering of the main lobe while some light amplitude modulation is observable due to remaining spectral components being improperly filtered. This is explained by the resolution limit set by the WSS used, however the reshaping can easily be improved by increasing the FFT order, using cascaded DLI or higher resolution WSS.

The clean channel obtained in path B was then interferometrically subtracted from the superchannel travelling path A. The maximum suppression was obtained only with exact time, polarisation and power alignment. The experimental laboratory environment induced phase drift in the interferometric structure so phase stabilisation circuit was implemented using a phase lock loop circuitry.

1.3 Experimental Results

Due to the discrete nature of the components used as well as the length of fibre used, the suppression function was stabilised with extinction ratio situated between 10 and 15 dB. Subsequently, penalty associated with this was observed when inserting the add channel. The path C is formed of a data source representing the channel to be added to the superchannel. Fig. 6 shows the spectrum at the input of the node, after the drop function and at the output of the node. While the power and polarisation were matched with the superchannel points, the time delay was aligned to a strict integer number of time period. The add channel was simply inserted in the vacant spectral slot obtained by the drop function.

Fig. 6 presents the Q-factor values obtained for the five central channels of an AO-OFDM superchannel at the input of the node and at the output. Error bars represent the standard deviation over 40 measurements of 160k samples and consequently the fluctuation in Q-factor due to the drop interferometer variation. In addition, maximum values from this set of measurement are presented to show the potential of such a scheme if integrated and/or fully stabilised.

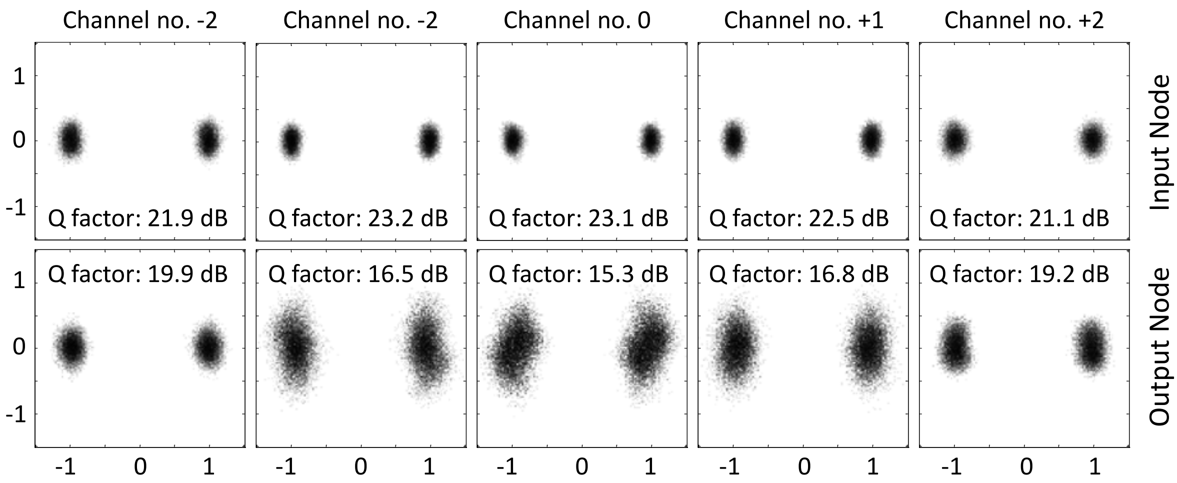

Fig. 7: Selected constellation diagram of the five central channels with Q factor close to average before and after the node

Fig. 7 displays the constellation diagram for Q-factor values close to the average, and shows the error free output of the TIDE node. Distortion and degradation are mainly attributed to the reshaping filter mismatch resulting in loss of orthogonal condition and the drop interferometer instability. As expected, the penalty for the central channel was greatest, however, the remained considerable margin above the FEC threshold, and we anticipate that the required OSNR penalty of this scheme at the FEC threshold would be small.

1.4 Conclusion

In this deliverable, we report great progress with the experimental implementation of a flexible all-optical node with drop and add function for channels embedded in possible terabit/s wide superchannel. We describe the first implementation of a TIDE node using an AO-OFDM superchannel. Channel extraction, drop, and insertion is demonstrated with Q factors well above the FEC threshold. The optically implemented scheme proposed scales to multi-Terabit/s superchannels and opens the way for up-coming guard-band free all-optical flexible transport networks.

1.4 References

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