Demonstration of Bit Rate Variable ROADM functionality on an Optical OFDM Superchannel

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Abstract: We demonstrate a bit rate variable add- and drop function performed on an optical OFDM superchannel signal by optical filtering and superposition of OFDM subbands and the application of different modulation formats for dynamic networks.
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1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a very promising modulation format for high-speed and high capacity optical transmission due to its high spectral efficiency and its resilience in the presence of fiber dispersion and PMD [1,2]. Due to the almost rectangular shape of the optical spectra of OFDM, multiple OFDM signals can be set close together without guard interval in frequency domain [3]. This feature can not only be used to achieve a high spectral efficiency, but also for narrow interleaving of OFDM subbands generated by locally distributed transmitters [4] without the need of generation of frequency- and phase locked optical carriers [5].

We propose to use continuous waveband signals based on optical OFDM subbands as a bit rate variable transmission format in dynamic networks. Beside the flexible configuration of each OFDM subband to adapt for different optical signal paths, several OFDM subbands can be merged together to superchannels, transporting a multiple capacity of an individual OFDM subband. In this paper we demonstrate a bit rate variable add- and drop function performed on a continuous waveband signal based on the optical filtering and superposition of various OFDM subbands and the application of different modulation formats, e.g. 8-QAM or 16-QAM.

2. ROADM for continuous waveband signals

Typically a continuous waveband signal based on OFDM shows negligible guard intervals in the frequency domain between the respective subbands. If optical filtering is required to perform drop- and add functions e.g. in a reconfigurable optical add drop multiplexer (ROADM), some residual signal of adjacent subbands beside the wanted or suppressed channels will remain due to the finite slope of the filter edges as indicated in fig. 1.

In the ‘drop’ path, the partly filtered adjacent subbands will be present besides the wanted channels, because of the square like shape of OFDM signals. Due to the high selectivity of optical coherent receivers in the proposed system, no additional penalty has to be taken into account, when the adjacent subbands are not completely suppressed.

For the ‘add’ function, first a band stop filter has to be applied to clean up the spectrum, where the new OFDM subbands will be added. However, the adjacent subbands of the express path may not be corrupted, so a transition area with some interfering signal power will remain, which can not be removed at the receiver. To avoid high penalties because of linear cross talk, the bandwidth of the added channels have to be smaller than the created spectral gap in the express path. However, we will demonstrate that the loss of spectral efficiency in this case may be compensated by the application of a higher constellation modulation format for the added channels.

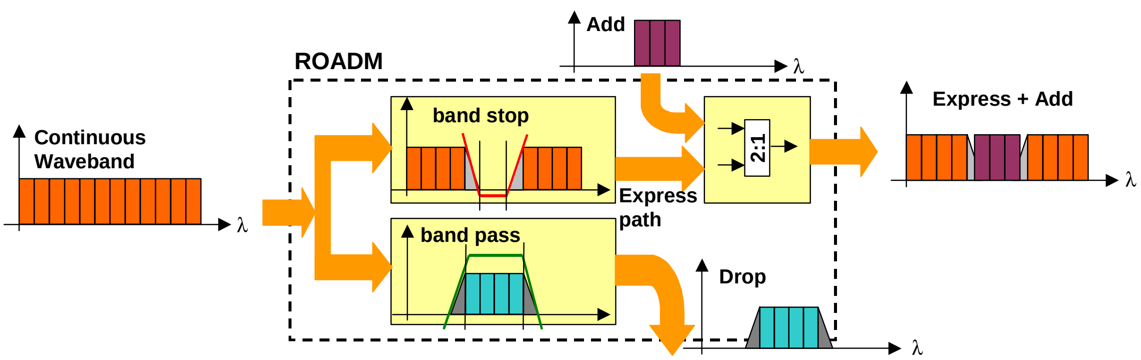

Fig. 1: *Principle setup for drop and add with a continuous waveband spectrum*

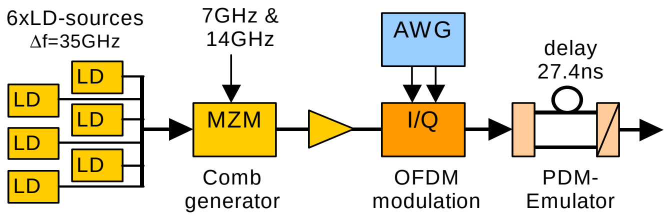

Fig.2a: Transmitter for 30x26Gb/s multiband OFDM signal,

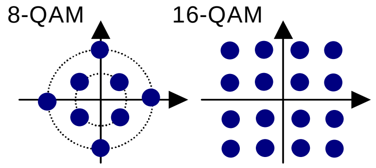

Fig.2b: Constellations of 8-QAM and 16-QAM modulation

3. Experimental Setup

Fig. 2 shows the transmitter setup for generation of a 30x26 Gb/s multiband OFDM signal. The 6 laser diode sources (LD) are placed on a 35 GHz grid. The outputs are combined and launched to a Mach-Zehnder modulator (MZM), which is driven by two sinusoidal signals with 7 GHz and 14 GHz, thus generating 30 equidistant optical lines with 7 GHz spacing. The 30 lines are modulated by an optical I/Q-modulator, which is driven by an arbitrary waveform generator (AWG). The AWG generates an offline calculated FFT based OFDM signal, consisting of 120 subcarriers, each modulated with 8 QAM in a star like constellation (Fig 2b). At the modulator output the signal is split, delayed by one symbol length of 27.4 ns and then superimposed with orthogonal polarisation. At the output of the transmitter we provide a continuous waveband signal, consisting of 30 PDM-OFDM subbands, each carrying a gross capacity of 26.3 Gb/s, which is a total net capacity for the transmitter of 720 Gb/s considering OFDM- and 7% FEC-overhead. The signal covers a bandwidth of approximately 210 GHz, so the spectral efficiency is 3.4 bit/s/Hz.

At the receiver side we use a coherent receiver setup with a tuneable laser as optical local oscillator and offline processing for frequency offset compensation, synchronisation, MIMO-processing for polarisation demultiplexing and bit error rate (BER) measurement [3]. In front of the optical receiver there was a tuneable optical band pass filter with 0.5nm bandwidth for ASE-noise rejection. As configurable filter, which is supposed to be located inside a ROADM, we used a commercial available wavelength selective switch based on liquid crystals on silicon (LCoS).

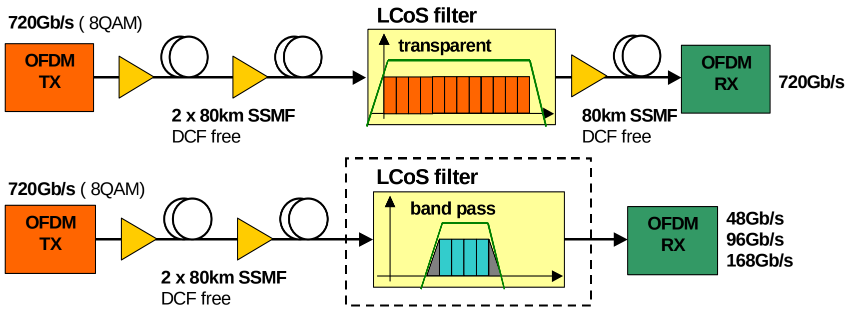

Fig. 3: Experimental setup for Q-factor measurement of reference (top) and 'drop'-channels (bottom)

In a first measurement the drop function of the ROADM is evaluated. As a reference the performance of all 30 subbands is measured after the transmission over 160 km SSMF in front and 80 km SSMF after the LCoS filter, which was set to a transparent mode as shown in fig. 3 top. The Q-factor derived from BER-measurements is above 9.9 dB (fig. 4b), indicating some margin vs. an assumed FEC limit of 9.1 dB. Then the LCoS-filter is configured as a band pass filter with a respective bandwidth of 15 GHz, 30 GHz and 50 GHz at varying center frequencies, thus filtering out 2, 4 or 7 OFDM subbands. This is equivalent to the drop of a variable bit rate channel with a net data rate of 48 Gb/s, 96 Gb/s and 168 Gb/s, respectively.

The filtered spectra of the dropped subbands are depicted in fig. 4a, showing some spectral shaping of the dropped channels by the filter and the residual signal power of adjacent subbands. However the corresponding Q-factor measurement fig. 4b indicates negligible degradation vs. the express configuration within the experimental

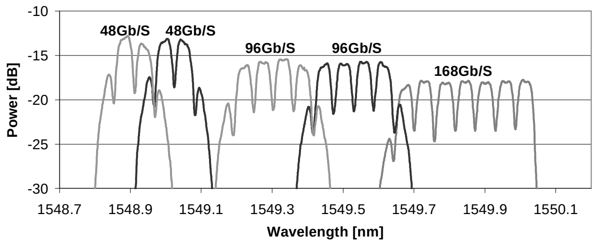

***Fig. 4a:** Spectra of various configurations of drop-channels for 48Gb/s, 96Gb/s and 168Gb/s*

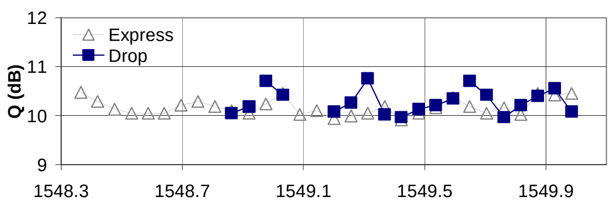

***Fig. 4b:** Q-factor of 'express'-channels(open triangles) and 'drop'-channels (squares)*

accuracy. This demonstrates the capability of the channel estimation of the OFDM receiver to compensate the linear distortion by the narrow optical filter and the rejection of unwanted adjacent signals by the coherent receiver.

Fig. 5 shows the setup to demonstrated an 'add' function. To allow the superposition of the continuous waveband signal with 3 OFDM subbands, provided by a second transmitter, the LCoS-filter is configured as band stop with a bandwidth of approx. 35GHz, thus creating a full gap of 21GHz bandwidth for 3 subbands with a transition area of 7GHz at each side of the gap, due to the finite filter slope. With a passive 3dB-coupler, the new subbands are added to the original signal and transmitted to the receiver.

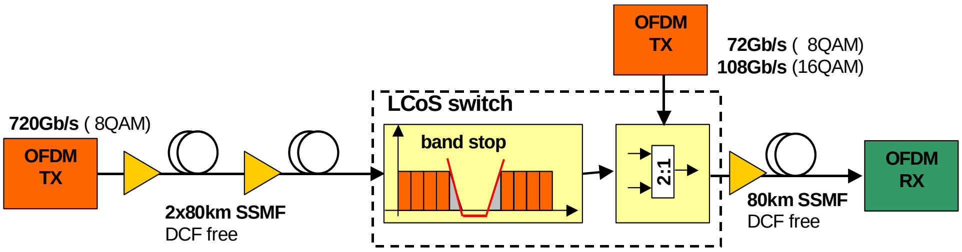

Fig. 5: Experimental setup for 'add' function

The spectrum of the superimposed signals after the combiner is shown in fig. 6a together with the transfer function of the band stop filter. The measured Q-factor of the added channels at the receiver is shown in fig. 6b. It is up to 3.5dB better than the reference (fig. 4b), which is attributed to the shorter transmission distance for these channels. The neighbouring channels of the express signal were also measured, but they did not show any penalty due to the band stop filtering. Naturally the two subbands resided at the edges of the band stop filter would show high penalties if further used for data transmission. This reduces the overall spectral efficiency of the setup. However, the data rate of the added OFDM channels can be increased by usage of a higher constellation modulation format like 16-QAM (fig. 2b). As shown in fig. 6b, the added 16-QAM channels achieve the same Q-factor performance of about 10dB as the reference configuration with 8-QAM. 16-QAM increases the net data rate of the three added channels to 108 Gb/s in 21 GHz-bandwidth, thus preserving 90% of the capacity of the originally used 5 subbands in a 35 GHz-bandwidth.

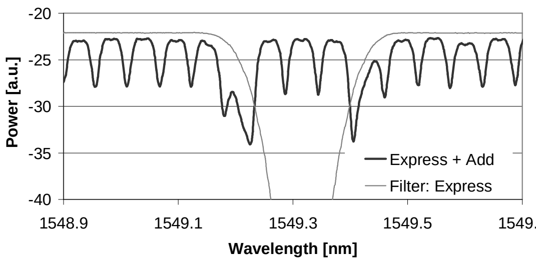

***Fig. 6a:** Spectrum of combined 'Express'- and 'Add'-channels and transfer function of band stop filter*

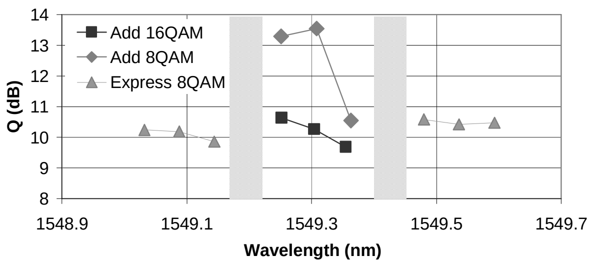

***Fig 6b:** Q-factor of 3 added subbands (8QAM or 16QAM) and neighbouring subbands of express path*

4. Summary

We have demonstrated a bit rate variable drop- an add function for continuous waveband signals based on optical filtering and superposition of OFDM subbands. We have shown that a narrow filtering of OFDM subbands with incomplete suppression of adjacent channels, can be detected in a coherent receiver without penalty. Due to the finite slope of available optical filters, the superposition of new channels in a previously used spectral window can not be achieved without a guard band, which reduces the overall spectral efficiency. However, we have demonstrated the application of a higher constellation modulation format to increase the data rate of the added subbands, thus maintaining the capacity of the transmission link.

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