Interleaving OFDM Signals for Multiple Access with Optical Routing Capability and High Spectral Efficiency

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Abstract *We propose interleaving of OFDM signals as a scheme for multiple access. By filtering of subbands a routing function is realised. The concept is demonstrated by transmission over 400km SSMF with spectral efficiency of 3.1bit/s/Hz.*

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 resistance to fiber dispersion and PMD [1,2]. Recently, 1.2-Tb/s transmission with spectral efficiency of 3.3 bit/s/Hz was demonstrated [3]. Due to the almost rectangular shape of the optical spectra of OFDM, multiple OFDM signals can be set close together [4]. This feature can not only be used to achieve a high spectral efficiency [3] but also for narrow interleaving of OFDM subbands generated by locally distributed transmitters.

In this paper we demonstrate novel narrow interleaving of OFDM subbands for a spectral efficient aggregation of 100[+] Gb/s signals generated by two independent transmitters without the need of coherence of the subbands [5]. The combined signals from both transmitters with a total capacity of 290.4 Gb/s are directed to two receivers by filtering in a 50-GHz grid showing that this approach can be efficiently used for multiple access systems with optical routing capabilities.

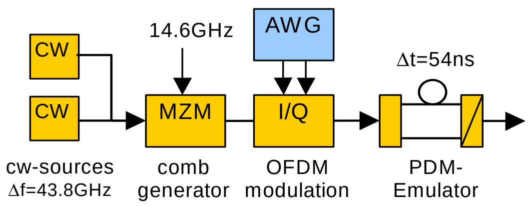

Fig. 1: FDM-OFDM-PDM Transmitter setup

Experimental setup

As shown in the system setup Fig. 2, two independent OFDM transmitters were used, each consisting of 2 cw-sources, a comb generator, OFDM data modulation and polarisation multiplexing (Fig.1). The two cw-sources of each transmitter were set to a frequency difference of 43.8 GHz. The comb generators, realized by Mach-Zehnder modulators (MZM), were driven by 14.6-GHz sinusoidal signals. This generates 3 lines out of each cw-source, resulting in total 6 lines with equidistant spacing of 14.6 GHz for each transmitter. Since the light sources of Tx B were offset by 7.3 GHz with respect to Tx A, the two spectra could be interleaved even after transmission over fiber, thus generating a continuous waveband frequency division multiplexing (FDM) OFDM signal, which covers a total bandwidth of 87.6 GHz, carrying 12 OFDM signals in equidistant spacing of 7.3 GHz.

The I- and Q- component of the OFDM signal were calculated offline and stored in a 10-GSa/s arbitrary waveform generator (AWG). The OFDM spectrum consisted of 340 subcarriers, from which 332 were modulated with QPSK. For dispersion compensation a cyclic pre- and postfix of 28 samples was introduced, resulting in a total OFDM symbol duration of 54 ns. Together with polarisation diversity multiplexing (PDM) each OFDM signal can transport a capacity of 24.2 Gb/s. The total capacity of both transmitters was 290.4 Gb/s, which leads to a usable spectral efficiency of 3.1 bit/s/Hz accounting 7% FEC overhead.

To achieve an optical routing functionality at the receiver side, the continuous waveband was split into a lower and a upper part by an optical filter. These subbands, each consisting of 6 adjacent OFDM tributaries, were directed to receivers Rx C and Rx D respectively. However, for bit error measurement we did not duplicate the receiver part of the setup. Instead we used the same coherent OFDM receiver and a tunable optical band pass filter with a bandwidth of about 50 GHz, stepping on a 50 GHz

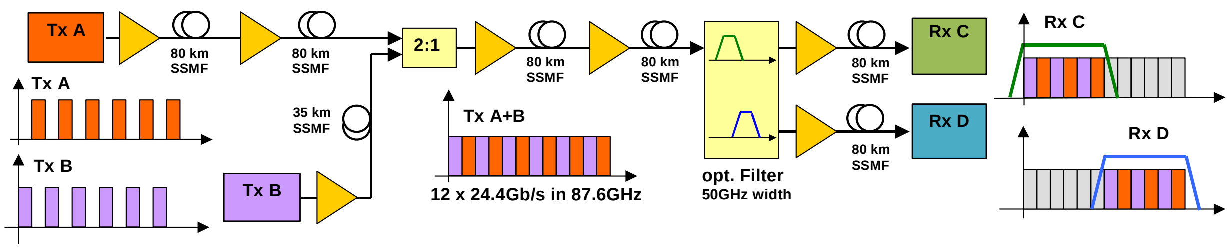

Fig. 2: Setup of multiple access system with interleaved OFDM signals and optical routing capability

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grid to filter out the respective subbands. The synchronisation, frequency offset correction, MIMO processing, OFDM demodulation and BER estimation at the receiver was performed offline.

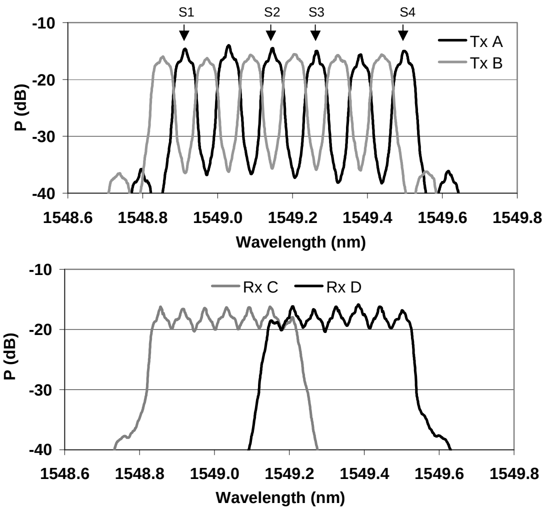

Fig 3: Spectra of Tx A and Tx B (top), and filtered subbands for Rx C and Rx D (bottom)

Fig. 3 shows the optical spectra of the two transmitters and behind the optical band pass filter for subband selection. Each OFDM signal covers a minimum bandwidth of 6.8 GHz. By choice of 7.3-GHz spacing between the OFDM signals, we introduce a guard band of 0.5 GHz to account for out of band noise and laser drift. Fig. 3 top shows, that the comb generation has a suppression of unwanted higher order lines of about 20dB.

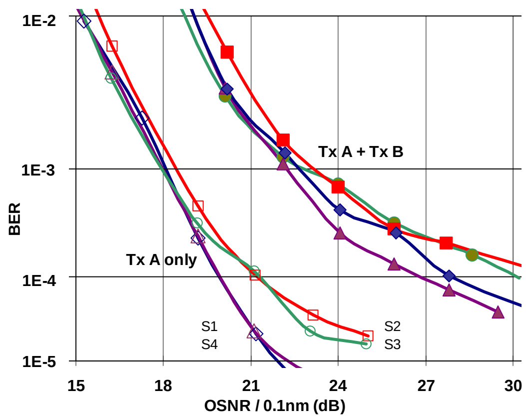

Fig 4: BER vs. OSNR back-to-back for Tx A only and Tx A and Tx B interleaved

Performance of interleaved OFDM signals

For an evaluation of the system performance, we measured BER vs. OSNR in back-to-back configuration for 4 different OFDM channels of Tx A, indicated by arrows in Fig. 3. The results are shown in Fig. 4 for Tx A only and when the output of Tx A and Tx B are interleaved.

Already without interleaving of signals ('Tx A only') we observe a dependency between BER performance and position of the respective OFDM signal within the regarded waveband. S2 and S3 suffer from additional linear cross talk due to the side lines of the comb generators.

Besides the expected increase of 3 dB in OSNR when the capacity is doubled ('Tx A + Tx B'), we observed an additional penalty of 1.5 dB due to the narrow interleaving of the OFDM signals.

Transmission and routing of OFDMA subbands

To evaluate the transmission and routing of the OFDM subbands we introduce several SSMF spans as already shown in Fig. 2. The Q-factor measurement of all 12 OFDM channels after transmission over 400 km and 275 km respectively is shown in Fig. 5.

A difference of 0.8 dB in Q-factor between Tx A and Tx B was measured. This can be attributed to the different length of the 'feeder' lines of 2x80 km and 35 km respectively. With OFDM this differences in performance by different OSNR levels can be compensated by gradually removing modulated subcarriers. In our set up a multirate OFDM configuration with 316 subcarriers in Tx A and 332 subcarriers in Tx B adjusted the Q-factor performance for both transmitters to the same level (Fig. 5). This reduces the total capacity of the system by about 7 Gb/s, however we still achieved a spectral efficiency of 3.0 bit/s/Hz.

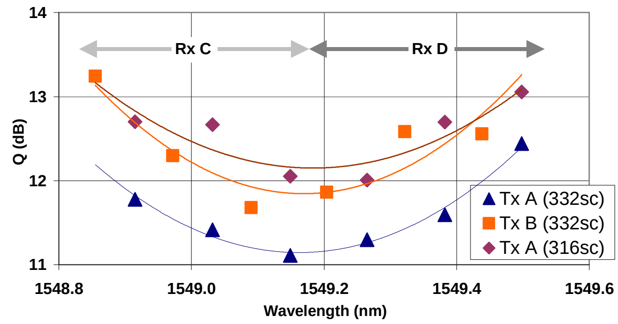

Fig. 5: Q-factor after transmission for Tx A (squares), Tx B (triangles) and Tx A with reduced number of subcarriers (diamonds), lines are 2^{nd} order polynomial fit

Summary

Narrow interleaving of OFDM subbands from locally distributed transmitters for spectral efficient multiple access and routing of OFDM subbands to different receivers was demonstrated. In addition the OFDM signals were adapted in capacity to achieve a uniform performance at the receiver side independent of differing noise accumulations, e.g. by different length of the feeder lines. Finally, we demonstrated the transmission over SSMF up to 400 km of narrow interleaved OFDM signals with a spectral efficiency of 3.1 bit /s/Hz and significant Q-factor margin.

References

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