Compact and Broadband Coherent Receiver Front-End for Complete Demodulation of a 1.12-Terabit/s Multi-Carrier PDM-QPSK Signal

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Abstract *We report a compact coherent receiver front-end consisting of an integrated 4x40 arrayed-waveguide-grating array following a polarization-diversity hybrid for complete demodulation of a 1.12-Tb/s multi-carrier-signal having 10x112-Gb/s PDM-QPSK subchannels, achieving 17-dB required OSNR/subchannel at BER=10^{-3}.*

Introduction

100-Gb/s Ethernet is currently under extensive research and development for next-generation Ethernet transport systems. Owing to its high sensitivity and capability to compensate for transmission impairments, digital coherent detection is considered as a promising technique for future 100-Gb/s systems, based on either single carrier[1,2] or multi-carrier transmission[3]. Recently, Terabit/s Ethernet was considered as a future direction for transport system evolution. However, the speed of the electronic analog-to-digital converter (ADC) needed in digital coherent detection is expected to be limited to well below 100 Gsamples/s for the foreseeable future. To resolve this electronic bottleneck issue, optical multiplexing techniques are necessary. With optical time-division multiplexing, demodulation of one out of the 32 tributaries of a 1.28-Tb/s OTDM signal was recently demonstrated[4]. Here, we propose and demonstrate a compact coherent receiver front-end for complete demodulation of a 1.12-Tb/s multi-carrier signal consisting of 10x112Gb/s polarization-division-multiplexed quadrature phase-shift keying (PDM-QPSK) subchannels spaced at 50-GHz, achieving low required optical signal-to-noise ratio (OSNR) of 17 dB/subchannel at bit-error ratio (BER) of 10^{-3}. To the best of our knowledge, this is the first coherent receiver front-end capable of simultaneous demodulation of all the tributaries of a Tb/s signal.

Principle and design

Fig. 1 shows the schematic of the proposed receiver front-end. The first key novel feature of this receiver is use of *only one* polarization-diversity hybrid, rather than 10 hybrids, for mixing all the subchannels with their corresponding optical local oscillators (OLOs), thereby greatly simplifying the optical front-end. The second key feature is the use of an integrated 4x40 arrayed waveguide grating (AWG) array to serve as wavelength demultiplexers (DMUXs) for complete separation of all the subchannels. The hybrid is based on free-space optics and has the advantages of being low loss, athermal, and wavelength independent over a broad wavelength range. The AWG-array consists of four 1x10 AWGs on a planar lightwave circuit with a size of 5.7cmx4cm, and is designed to be cyclic every 500 GHz so that this receiver front-end can receive any such multi-carrier signal over a broad wavelength range. The path lengths of its 40 outputs were matched within ±0.1mm. The input and output ports of the 4x40 AWG array were fiber-pigtailed and connectorized. Fig. 2 shows the measured fiber-to-fiber transmittance at each of the 40 output ports of the AWG array. Over the C-band, the average loss at the passband centers is 3±0.2 dB. It is important to align the passbands of the four AWGs. We achieved accurate alignment of the passband center frequencies of the four AWGs to within ±2 GHz, as indicated in Fig. 2. The passbands are of 1st-order Gaussian type with a 3-dB bandwidth of 32±2 GHz.

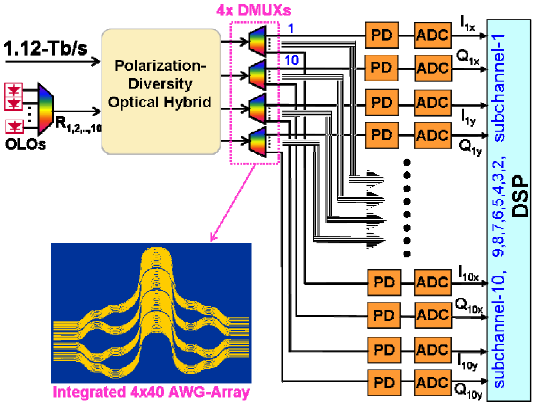

Fig. 1: Schematics of the proposed 1.12-Tb/s receiver setup. The inset shows the layout of the 4x40 AWG array.

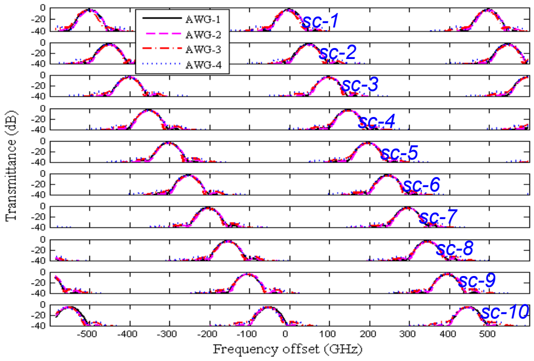

Fig. 2: Measured passbands of the 10 output ports of each of the 4 AWGs. The center frequency of each passband is aligned to that of a particular subchannel (sc).

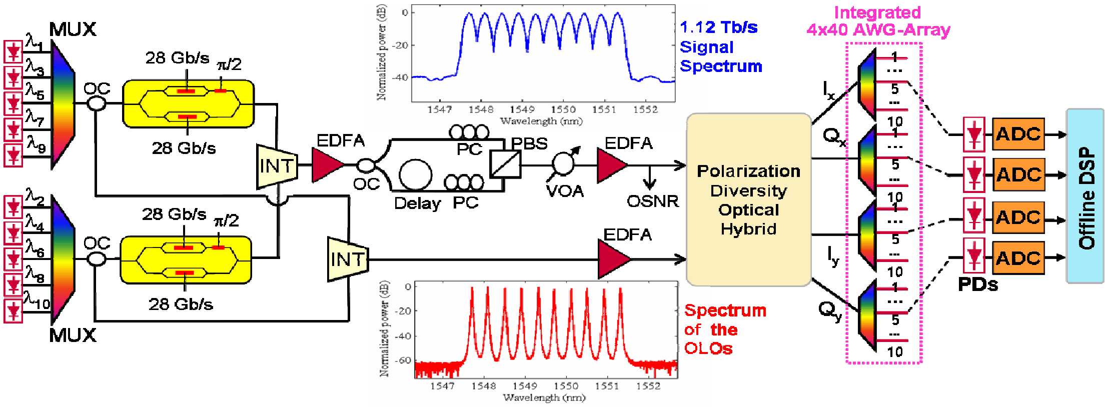

Fig. 3: Experimental setup of the generation and detection of the 1.12-Tb/s multi-carrier signal. Insets are the measured optical spectra of the signal and the OLOs. MUX: multiplexer; INT: interleaver; OC: optical coupler; PBS: polarization-beam splitter.

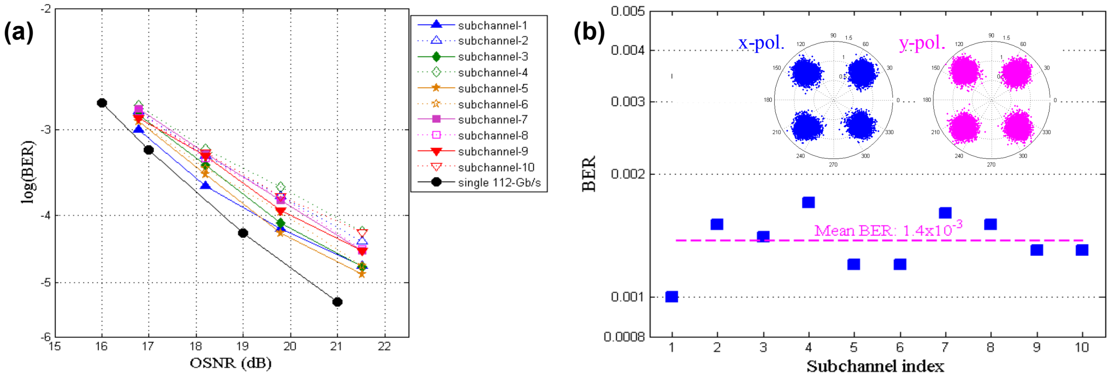

Fig. 4: Measured BER performance of each of the 10 subchannels of the 1.12-Tb/s multi-carrier signal as a function of (a) OSNR and (b) subchannel index at mean OSNR=16.8 dB. Insets in (b) show typical recovered constellations at 35-dB OSNR.

Experimental setup and results

Fig. 3 shows the experimental setup. Ten lasers with 100-kHz linewidth were used as the light sources. The 1.12-Tb/s multi-carrier signal contained ten 50-GHz spaced 112-Gb/s PDM-QPSK subchannels with the even and odd subchannels being modulated by two separate I/Q modulators before being combined by a 100/50-GHz interleaver. Polarization multiplexing was achieved by first splitting the signal into two paths and then recombining them in a PBS, using polarization controllers (PCs) and a 431-symbol decorrelation delay. The drive signals were PRBS of length 2^{15}-1. The signal was attenuated by a variable optical attenuator (VOA) before an EDFA to vary the received OSNR, before entering the signal-port of the hybrid. A copy of the 10 lasers entered the OLO-port of the hybrid. After coherent mixing, the four outputs of the hybrid were connected to the 4x40 AWG array. At the 40 outputs of the AWG-array, simultaneous demodulation of all the signal tributaries of the 1.12-Tb/s signal is completed. The BER performance of the entire 1.12-Tb/s signal was measured one subchannel at a time by connecting the four outputs associated with each subchannel to four photo-detectors, which were followed by four 50-GS/s ADCs in a Tektronix real-time sampling scope. Sampled waveforms of length 2x10^6 each were stored and processed offline with typical digital coherent detection processes[5], which included blind equalization for polarization de-multiplexing. Fig. 4(a) shows the measured BER performance as a function of OSNR. Here the definition of OSNR follows the convention of the signal power divided by the noise power in a 0.1-nm bandwidth. All ten subchannels perform similarly, and at BER=10^{-3}, the mean required OSNR is 17 dB/subchannel, which is 0.5 dB higher than that for a single 112-Gb/s signal, indicating small penalty due to the combined use of the shared hybrid and the AWG array. Error-free operation was achieved at high OSNR. Fig. 4(b) shows the BERs of the ten subchannels at OSNR=16.8 dB, showing similar performance across the subchannels. We also verified similar BER performance when the signal was tuned inside the C-band.

Conclusions

We have demonstrated a compact/broadband coherent receiver front-end for complete demodulation of a 1.12-Tb/s multi-carrier signal, which may serve as a step towards the practical implementation of future Terabit/s Ethernet.

References

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