Hybrid Electro-Optical MCM as Multi-Flow Generation Enabler for Elastic Optical Networks

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The advent of elastic optical networking, enabled by the adoption of the flexible channel grid and programmable/multi-flow transmission systems allows a dynamic management of optical networks. Multicarrier modulation (MCM), such as orthogonal frequency division multiplexing (OFDM), arises as a suitable technology for increasing flexibility and advanced functionalities, thanks to its super-/sub-wavelength granularity [1].

In this paper, we propose a hybrid electro-optical spectral efficient MCM scheme, where multiple OFDM electrical signals/flows are de/multiplexed into a superchannel by optically implementing the discrete wavelet packet transform (DWPT) and its inverse (IDWPT) [2]. The proposed transmission scheme is depicted in Fig. 1a.

Fig. 1 (a) Schematic diagram of the hybrid electro-optical MCM scheme. (b) BER of S1 using either an SSS or a coupler.

For the optical superchannel generation, K orthogonal carriers, with spacing Δf , can be created using a single laser source and a comb generator. Alternatively, cost/power efficient schemes, such as multi-wavelength locked lasers and planar lightwave circuits (PLC), can be adopted [3]. The resulting subcarriers are demultiplexed, to independently drive optical modulators, with a suitable optical filter. For the electrical signal generation, MCM signals are created at the digital signal processing (DSP) block and digital-to-analog converted, by means of a digital-to-analog converter (DAC), to be later modulated with the optical carriers. After modulation, the array of MCM signals are orthogonally multiplexed, in order to create a superchannel, by adopting the IDWPT, which can be implemented using PLCs. The transform consists of a chain of half-band/quadrature mirror filters, which can be synthesized by using cascaded Mach-Zehnder interferometers (MZI) [5]. An example of the optical architecture corresponding to a 2-level Haar wavelet is depicted in Fig. 1a. The MZIs can be integrated employing silicon-on-insulator technology enhancing power efficiency. Alternatively, the IDWPT/DWPT can be performed with programmable spectrum selective switches (SSS), by selecting the appropriate attenuation/phase of each port to fix the transfer function of the concatenated wavelet filtering stage. Additionally, the SSS can be placed at the network nodes, allowing the control plane to efficiently implement the suitable wavelet function depending on the network condition. Different wavelet bases can be selected achieving different nonlinearity performance and polarization mode/chromatic dispersion tolerance [2]. At the receiver side, the DWPT, an optoelectronic front-end and analog-to-digital converters (ADC) are considered. For the proof-of concept, we implement a cost-effective scheme based on direct detection. Two double side band OFDM 20GHz signals are digitally generated with a 512-point inverse FFT and converted to analog with a 64GS/s DAC. Both uniform and bit/power loading (BL/PL) are implemented [4]. Two orthogonal carriers are generated and filtered with a 12.5GHz SSS. The resulting optical tones drive two external Mach-Zehnder modulators (MZMs). For the IDWPT/DWPT implementation, either a 3 dB coupler or an SSS with a π phase shift between the two inputs are used to optically create the superchannel. Both solutions, present the same transfer matrix of a single Haar-based WP stage [5]. The received signals are independently photodetected with a PIN (front-end) and converted to digital with a 100GS/s real-time oscilloscope (as ADC). A BER of 3×10^{-3} , corresponding to hard-decision forward error correction (HD-FEC) (7% overhead) is considered. The two OFDM signals (S1 and S2) have been successfully packed into a superchannel by using the 3dB coupler (Fig. 1a). The BER is below the HD-FEC threshold in B2B and after 10km of standard single mode fiber, as seen in Fig. 1b, which depicts S1 results. By replacing the coupler with a programmable SSS, configured to implement the single Haar wavelet, similar BER performance is achieved. Hence, by programming the SSS with a suitable wavelet, IDWPT/DWPT can be optically implemented enabling to efficiently pack multiple flows.

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