Modulation-Format Transparent Optical Arbitrary Waveform Generation Based Optical-Label Switching Transmitter with All-Optical Label Extraction Using FBG

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Abstract: This paper shows a modulation-format transparent optical-label switching transmitter based on optical arbitrary waveform generation. Every generated packet consists of a payload and a label; labels are extracted by a fiber Bragg grating.

Optical-label switching (OLS) is a promising technology for implementing future all-optical packet switching networks [1]. OLS processes payloads all-optically while allowing both optical and electrical processing of labels through label extraction and rewriting. Among the many optical labeling schemes, subcarrier multiplexed labeling facilitates relatively simple all-optical extraction and rewriting by placing encoded labels as spectral components [2]. Modern optical networks simultaneously demand high data rates, high spectral efficiency, high capacity and low latency; however, the modulation and the spectral placement of the optical labels of the current subcarrier modulation method restrict the modulation format and bandwidth of the data payload and thus constrain network evolution.

Recent developments in optical arbitrary waveform generation (OAWG) allow for a new approach to OLS. OAWG can be used to create complex OLS packets, each consisting of a payload and a label in arbitrary modulation formats. OAWG is based on the parallel line-by-line manipulations of an optical frequency comb (OFC), which can generate spectrally efficient OLS packets. The maximum data rate of the OLS packets is determined by the total spectral bandwidth of the OFC. Static intensity and phase manipulations on each optical comb line generates identical OLS packets that repeat at the comb line frequency spacing. Using time-varying intensity and phase modulations makes it possible to generate infinite length OLS packets provided that the modulators have bandwidths equal to the comb frequency spacing [3]. OAWG based OLS transmitter can exploit low-speed and independent modulations of the OFC to independently generate optical labels and data payloads of high data rates with any format.

In this paper, we experimentally demonstrate an OAWG based OLS transmitter by generating 100 ps duration repetitive OLS packets with 10-bit 100 Gb/s payloads (1011100110) and 4-bit 40 Gb/s labels (0110). The experiment also demonstrates all-optical extraction of the optical labels from the packets by using a fiber Bragg grating (FBG).

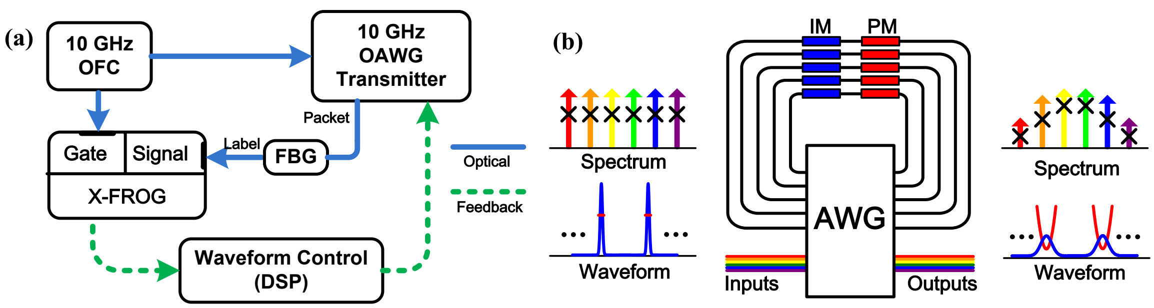

Fig. 1. (a) Experimental arrangement for the generation and separation of optical-label switching packets with 10-bit 100 Gb/s payloads and 4-bit 40 Gb/s labels. OFC: optical frequency comb; OAWG: optical arbitrary waveform generation; X-FROG: cross-correlation frequency resolved optical gating; DSP: digital signal processing. FBG: fiber Bragg grating. (b) A loopback AWG based waveform shaper. IM: intensity modulator; PM: phase modulator; AWG: arrayed-waveguide grating.

Fig. 1(a) shows the experimental arrangement. A dual-electrode Mach-Zehnder modulator and a phase modulator modulate a single-frequency 1550-nm laser, and generate an OFC of 33 spectral lines. The comb line spacing is 10 GHz, which corresponds to a repetitive pulse train with a period of 100 ps and a pulse width of 3 ps. Intensity and phase adjustments of each comb line are performed using integrated thermo-optic modulators based on resistive heaters. More than 20 dB of intensity extinction and 2π rad of phase shift can be achieved with this 10 GHz silica AWG based waveform shaper (WS) [4]. The OAWG transmitter generates the OLS packets, from which an FBG extracts the labels [5]. Cross-correlation frequency-resolved optical gating (X-FROG), a phase sensitive measurement technique [6], is used to obtain the complete intensity and phase information of the extracted label waveforms. The waveform control, or digital signal processing (DSP), compares the measured intensity and phase against target values, and adjusts intensity and phase modulator settings in an iterative fashion in order to approach the target waveform [3].

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Fig. 1(b) shows a single loopback arrayed-waveguide grating (AWG) acting as the WS for the experiment [4]. The AWG first works as a demultiplexer, assigning each comb line onto a discrete waveguide according to its frequency. Then, intensity and phase modulators (IMs and PMs) adjust each comb line individually to exactly replicate the target intensity and phase. Finally, the same AWG acts as a multiplexer and combines all the spectral lines to yield the desired OLS waveform packet [4].

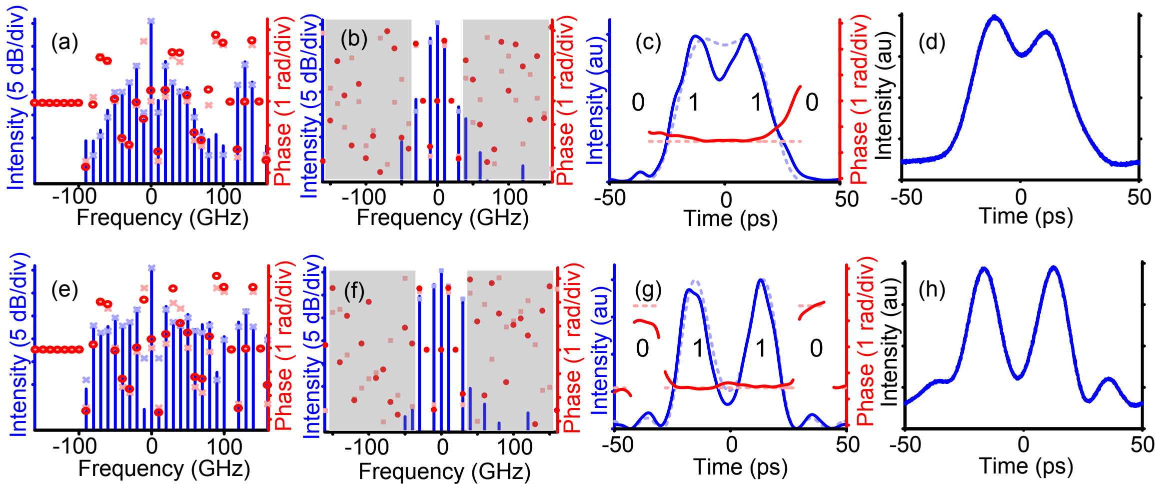

Fig. 2. Label extraction results (target intensity: blue "x" or blue dashed line, measured intensity: blue stem or blue solid line; target phase: red "x" or red dashed line; measured phase: red circle or red solid line). NRZ-OOK: (a) packet spectrum, (b) label spectrum, (c) label waveform and (d) label detected by oscilloscope. RZ-OOK: (e) packet spectrum, (f) label spectrum, (g) label waveform and (h) label detected by oscilloscope.

In the experiment we implemented an OAWG based OLS transmitter, in which an OLS packet with a 10-bit 100 Gb/s payload (1011100110) and 4-bit 40 Gb/s label (0110) were generated in both NRZ-OOK and RZ-OOK modulation formats. The single-sideband subcarrier multiplexing (SSB-SCM) scheme with a subcarrier frequency of 130 GHz was used as the labeling method.

Fig. 2 is the label extraction results for NRZ and RZ OOK formats. Fig. 2(a,e) shows the target and measured packet spectra. For each OLS packet, the payload occupies the baseband, while the label lies in the upper sideband. Fig. 2(b,f) compares the spectra of the target label with the extracted label. Due to the FBG's limited extinction ratio (~20 dB), some comb lines are not suppressed completely, as shown in the shadowed area. Additional filtering (software) is used to get rid of the extra comb lines, and Fig. 2(c,g) shows the corresponding time domain waveforms measured by X-FROG. The small deviations between the measured and target waveforms are largely due to shaping error. Fig. 2(d,h) shows the label waveforms detected by a 50-GHz-bandwidth oscilloscope as references to Fig. 2(c,g). The X-FROG-retrieved and the oscilloscope-detected label waveforms are not identical because the oscilloscope-detected label does not go through the additional filtering process. The recovered label waveforms from X-FROG (Fig. 2(c,g)) and the oscilloscope (Fig. 2(d,h)) both demonstrate the success using an FBG to perform label extraction of the OLS packets which are generated by an OAWG based OLS transmitter.

We have proposed and realized a highly versatile OAWG based OLS transmitter capable of supporting payload and label modulation in any modulation format. Experimental results show the success of generating OLS packets and extracting the labels for two different modulation formats using an FBG. This indicates the potential for an OAWG based transmitter to serve the needs of next generation all-optical packet switching networks.

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