Optical Fiber Technology 17 (2011) 141–144

Contents lists available at ScienceDirect

Optical Fiber Technology

www.elsevier.com/locate/yofte

Coherent spectral amplitude coded label detection for DQPSK payload signals in packet-switched metropolitan area networks

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ARTICLE INFO

Article history:
Received 26 May 2010
Revised 13 November 2010
Available online 22 February 2011

Keywords:
Optical packet switching
DQPSK
SAC labeling
Metropolitan networks
Coherent detection

ABSTRACT

We report on an experimental demonstration of a frequency swept local oscillator-based spectral amplitude coding (SAC) label detection for DQPSK signals after 40 km of fiber transmission. Label detection was performed for a 10.7 Gbaud DQPSK signal labeled with a SAC label composed of four-frequency tones with 500 MHz spectral separation. Successful label detection and recognition is achieved with the aid of digital signal processing that allows for substantial reduction of the complexity of the detection optical front-end.

1. Introduction

Packet switching provides high network resource utilization efficiency and is used in the conventional IP networks. The appearance of bandwidth-demanding services and subsequent growth of bandwidth capacity in the access network segment are expected to cause the data streams going through the metro area network (MAN) nodes to reach tens of Tb/s [1]. Both complexity and power consumption of the conventional routing nodes (factually, conventional IP routers with optical front-ends) are reaching the point where it becomes obvious that a new approach is required in order to help MANs keep up with the data streams from the access networks [2].

Optical packet switching (OPS) is considered a promising approach capable of increasing packet routers capabilities by reducing the amount of optical to electrical conversions and offering optical bypass of high speed signals [3]. However, an efficient solution is required for labeling of high speed optical payload signals.

Spectral Amplitude Coding (SAC) label is one of the realizations of optical labeling: a SAC label is a group of continuous waves at particular wavelengths. Power level of each of those wavelengths – spectral tones – represents a “one” or a “zero” [4]. As none of the label tones are modulated, their spectral width is very low: they are more resistant to dispersion, and their effect on the payload signal is minimal, so the SAC label occupies the same wavelength channel as the payload.

State-of-the-art setups for SAC label detection rely on an array of optical correlators to detect either individual spectral tones or complete label combinations [5,6]. Such an approach utilizes rather complex components – optical correlators – which feature a number of drawbacks: they require substantial power levels in order to operate, so the label has to be amplified. Another drawback is caused by the fact that such a correlator is a planar waveguide structure designed and built for a particular label tone wavelength, which makes correlator-based SAC label detection systems incapable of label reconfiguration, and makes such systems intolerant to label misalignment.

Quadrature phase-shift keying (QPSK) is one of the signal formats which is believed to become the standard for MAN networks: it is robust and has high spectral efficiency [7], so it can be used for long-range transmission of 100 Gb/s signals within the standard 100 GHz ITU-T grid, and polarization division multiplexing (PDM) technique is capable of doubling the bit rate. But in order to reliably receive QPSK signals at such bandwidths, coherent detection with the aid of digital signal processing (DSP) has to be employed in order to recover the phase information and compensate for the transmission impairments. Burst-mode detection of QPSK signals with DSP-assisted coherent receivers has been demonstrated for high-bit rate packets [8], and implementation of a flexible label detection technique which shares the operation principle with those receivers is a logic next step towards overall system unification and simplification.

In this paper, we propose a novel technique for SAC label detection employing coherent detection with a wavelength-swept local oscillator (LO) assisted by digital processing. The proposed method provides flexibility of reconfiguration and additional reliability of

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doi:10.1016/j.yofte.2011.01.001

detected labels through respective DSP algorithms. We also experimentally demonstrate SAC label detection and recognition for a SAC-labeled 10.7 Gbaud differential quadrature phase-shift keying (DQPSK) signal. The following section describes the operation principle of our proposed system. Next section contains the experimental setup description and the experimental results.

2. System description and discussion

The following principle is utilized in our proposed setup to detect the SAC labels: the signal containing both payload and a SAC label (Fig. 1a) is mixed with a continuous wave (CW) from the local oscillator (LO). The LO frequency is periodically linearly swept, as presented in Fig. 1b: the LO frequency oscillates around the frequency range covering expected spectral tone frequencies f_1 through f_4, so that the mixing product contains spectral components produced by mixing of the spectral tones with the LO (label products).

Since the LO frequency is swept in a linear fashion, the spectral position of the label products in the mixing product varies in a linear fashion as well. After applying a narrow pass-band filter positioned within the frequency range covering expected spectral tone frequencies f_1 through f_4 to the mixing product, an image of the SAC label in time domain is obtained. In our proposed setup, we acquire samples of the mixing product, and perform digital signal processing by applying a narrow digital pass-band filter to the obtained samples and detecting an envelope to create an image of the SAC label (Fig. 1c).

Digital signal processing (DSP) for label recognition has a significant advantage: it provides the flexibility for label structure rearrangement – through the possibility to change the pass-band filter position and width, the setup can be optimized for given label tone spacing, and LO central frequency and sweep range can be adjusted to handle SAC labels with a different spectral position and occupying a different spectral range. Additional processing is then applied to the obtained signal: time (for label tone position) and amplitude thresholding is performed to recognize the label.

SAC-labeled signal structure is presented in Fig. 1d: the SAC label is transmitted over the whole packet duration, and multiple scans may be performed for a single label to improve the reliability of label recognition through redundancy. Due to the linear nature of the LO frequency sweep, the resulting image will have inverted images of the SAC label in time domain (Fig. 1c).

3. Experimental description and results

We assessed the quality of the labels after detection. Since label tones are converted from spectral components into electrical amplitudes in time domain, resulting electrical signal SNRs were measured and used to evaluate the detected label tones quality. Measured SNRs were then plotted against the input optical SNRs to present the relation between the input and the output signal quality.

In our experiment, a 10.715 Gbaud DQPSK signal was labeled with a four-tone SAC label, representing a 4-bit binary label. The experimental setup is presented in Fig. 2. The spectral separation between the label tones was 500 MHz, making the overall SAC label spectral width 1.5 GHz. Four tunable DFB lasers with linewidths of less than 10 MHz centered around 1550.380 nm, offset from one another by 500 MHz, were used as a SAC label source. The outputs of the lasers were polarization-aligned with polarization controllers and combined in a 4-by-1 power combiner. A dual Mach–Zehnder IQ modulator was used to modulate the output of a tunable laser with the DQPSK payload. The output of the payload laser with a linewidth of about 200 kHz at 1550.362 nm was

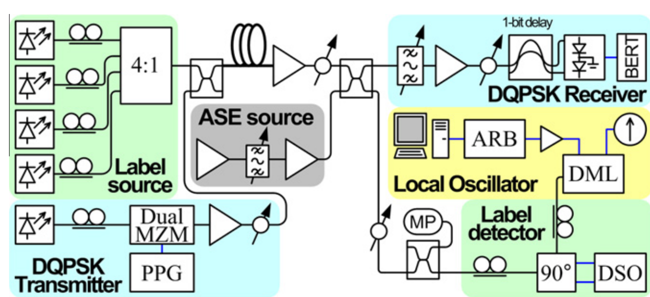

Fig. 2. Experimental setup configuration. PPG – pulse pattern generator; Dual MZM – dual Mach–Zehnder interferometer based modulator; ARB – arbitrary waveform generator; DML – direct modulated laser (used as an LO laser); BERT – bit error rate test-set; 90° – 90° optical hybrid coherent receiver; DSO – digital sampling scope.

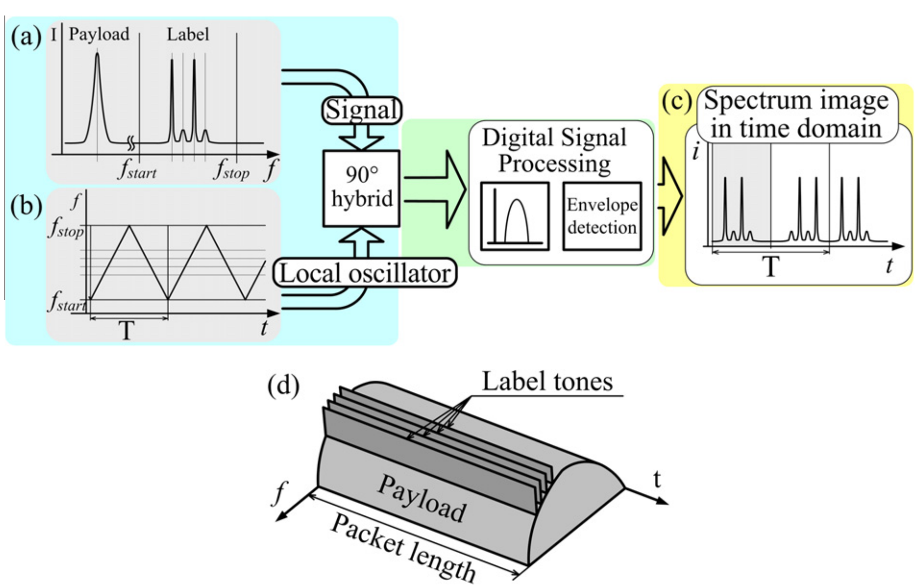

Fig. 1. Swept LO-based label detection principle: (a) SAC label spectrum; (b) swept LO f(t) diagram; (c) recovered electrical representation of the SAC label; (d) packet structure – payload and SAC labels.