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Labeling of 40 Gbit/s DPSK Payload using In-band Subcarrier Multiplexing

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Abstract: The transmission feasibility of 40 Gbit/s DPSK payload with in-band SCM labeling at 3 GHz subcarrier frequency is experimentally verified over 80 km NZDSF.

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1 Introduction

Optical Label Switching (OLS) has been proposed to enable more effective and flexible utilization of the capacity of WDM optical networks. Various methods of implementing this general concept have been proposed including “orthogonal” labeling [1], time-serial labeling and subcarrier multiplexing (SCM) [2]. The efficiency of conventional SCM labeling with the label placed out-of-band compared to the payload spectrum has been demonstrated for payloads up to 10 Gbit/s [2]. Upgrading of the payload bit rate to e.g. 40 Gbit/s using this technique will result in reduced spectral efficiency and increased cost of the label transmitter and receiver due to the high subcarrier frequency required. In parallel, the differential phase shift-keying (DPSK) modulation format has been reported to offer superior transmission properties such as improved robustness to fiber nonlinearities compared to the intensity modulation (IM) format, as well as enhanced receiver sensitivity when balanced detection is used [3]. The in-band SCM labeling of DPSK payload proposed in [4] takes advantage of the attractive properties of the DPSK format and additionally offers superior spectral efficiency. Similar spectral efficiency can be achieved with an in-band IM labeling scheme as proposed in [5]. But SCM labeling offers a number of additional benefits. These benefits include the possibility of attaching additional labels or tones to the payload signal. This feature can be utilized e.g. for signaling as proposed in [6]. Additionally, the SCM labeling potentially allows access to the label information of all channels transported in a fiber from one optical tap if each channel is attributed a different subcarrier frequency.

In this paper, we demonstrate the transmission feasibility of the in-band SCM labeling scheme with 40 Gbit/s DPSK payload and show that the subcarrier frequency can be reduced to only a few GHz at the cost of only moderate payload receiver penalty compared to the conventional out-of-band SCM labeling. Operating at such relatively low subcarrier frequencies keeps the components handling the SCM label signal simple and cheap.

2 Experimental set-up

The experimental set-up is shown in Fig. 1. A continuous wave laser at 1554.9 nm is intensity modulated with an electroabsorption modulator (EAM) to impose the SCM label signal. The EAM is driven with root-mean-square voltages ranging from 0 to 150 mV, corresponding to modulation depths between $\eta = 0$ and $\eta = 0.45$. The modulation depth is defined here as $\eta = (I_0 - I)/I_0$, where I is the transmitted intensity and I_0 is the value of I with no EAM driving signal applied. The modulating signal is a 25 Mbit/s SCM label at a subcarrier frequency of 1, 2 or 3 GHz. The signal is then amplified in an erbium-doped fiber amplifier (EDFA) before being phase modulated in a LiNbO₃ phase modulator with the 40 Gbit/s payload. The modulation signal is in the non return-to-zero (NRZ) format based on a $2^{31} - 1$ pseudo-random data sequence. The payload can therefore be considered constant envelope DPSK encoded. In the transmission

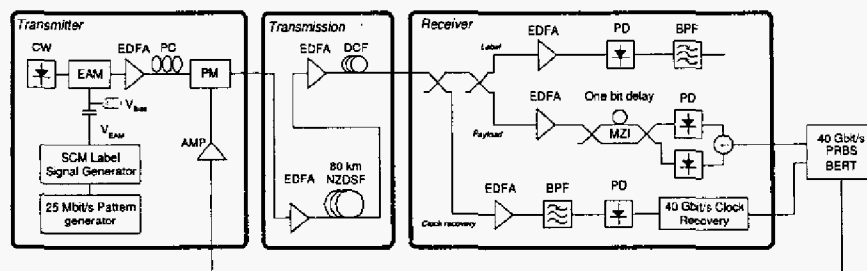


Fig. 1. Experimental set-up. CW: continuous wave laser; EAM: electroabsorption modulator; PC: polarization controller; PM: phase modulator; Att: attenuator; EDFA: erbium-doped fiber amplifier; NZDSF: non-zero dispersion shifted fiber; DCF: dispersion compensated fiber; BPF: optical band-pass filter; MZI: Mach-Zehnder interferometer; PD: photodiode; BERT: bit-error-rate test set.

experiment, the labeled signal is transmitted over 80 km of non-zero dispersion-shifted fiber (NZDSF) with a dispersion parameter of 5.7 ps/nm/km. The signal is dispersion post-compensated with a matching length of dispersion compensating fiber (DCF). The fiber span has a total span loss of 23.5 dB, which is compensated for by two EDFAs. At the receiver, a small part of the signal is tapped for clock recovery. An optical band-pass filter performs phase-to-intensity modulation conversion, allowing recovery of the 40 GHz clock. The main part of the received signal is split between the label and payload receivers. The DPSK payload is pre-amplified and demodulated with a one bit delay Mach-Zehnder interferometer (MZI - provided by ITF Optical Technologies). The signal is detected with a balanced receiver using two 45 GHz photodiodes and input to a 40 Gbit/s bit-error-rate test set (BERT). The SCM label is pre-amplified, detected and electrically band-pass filtered.

3 Experimental results

In the back-to-back case (when no transmission fiber is present) the DPSK payload eye diagrams and the corresponding detected SCM label signals for nine combinations of subcarrier frequencies (1, 2 and 3 GHz) and EAM driving voltages (50, 100 and 150 mV, leading to modulation depths η of 0.17, 0.33 and 0.45, respectively) are shown in Fig. 2. An increase in the EAM driving voltage corresponds to an increase in the SCM label modulation depth. Therefore, as the EAM driving voltage increases, the DPSK payload eye closes and the detected label signal amplitude increases, as seen in Fig. 2. Further, it can be seen that the DPSK payload eye closes as the sub-carrier frequency decreases, while the envelope of the detected SCM label appears unaffected. The degrading effect of the in-band SCM labeling on the DPSK payload is thus enhanced with lower subcarrier frequencies. The back-to-back DPSK payload receiver penalty as a function of the EAM driving voltage is shown in Fig. 3 (solid line) with a 3 GHz subcarrier frequency. The 0 dB penalty reference is the back-to-back receiver sensitivity at a bit-error-rate of 1×10^{-9} without any EAM driving voltage, which is -24.0 dBm. This sensitivity, when no degrading effect is induced by the subcarrier on the payload, corresponds to the best that would be achieved in our system in the case of conventional

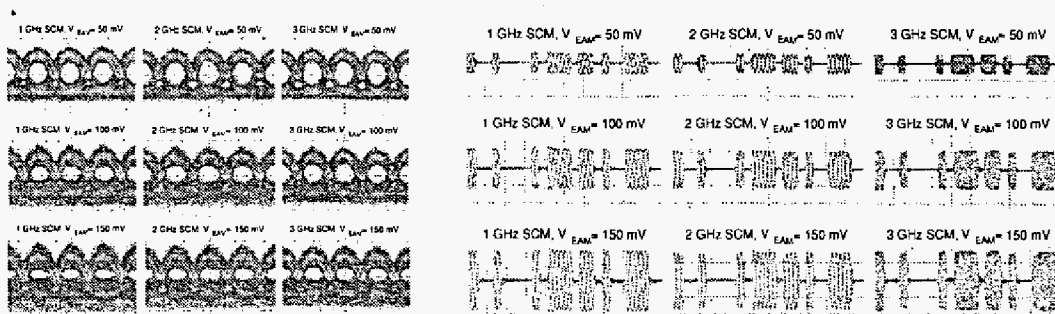


Fig. 2. DPSK payload eye diagrams (left) and corresponding detected SCM label signals (right) for nine combinations of subcarrier frequencies (1, 2 and 3 GHz) and EAM driving voltages (50, 100 and 150 mV). The horizontal axis has 10 ps and 10 ns per division for the payload and label, respectively and the eye diagrams are recorded in a 70 GHz bandwidth.

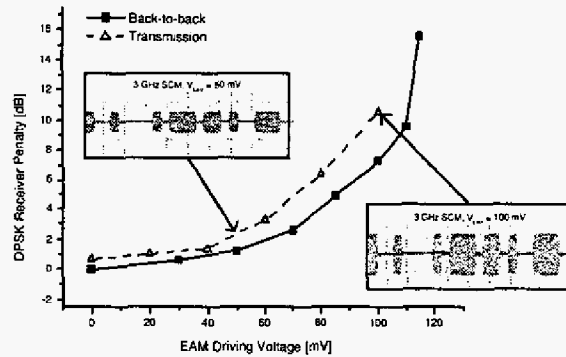


Fig. 3. DPSK payload receiver penalty as a function of EAM driving voltage back-to-back (solid line) and after transmission over 80 km of post-compensated NZDSF (dashed line). The inset shows the detected label signal after transmission at EAM driving voltages of 50 and 100 mV. The subcarrier frequency is 3 GHz.

out-of-band SCM labeling.

As expected, increasing the EAM driving voltage introduces some penalty. However, at an EAM driving voltage of 50 mV, corresponding to a modulation depth of $\eta = 0.17$, the penalty is limited to only 1.2 dB. Further, the transmission feasibility of the in-band SCM labeling of 40 Gbit/s DPSK payload is demonstrated with transmission over 80 km of post-compensated NZDSF using a subcarrier frequency of 3 GHz. The DPSK payload receiver penalty as a function of the EAM driving voltage is also illustrated in Fig. 3 (dashed line). The transmission introduces additional penalty. At 0 mV EAM driving voltage (without a label or the SCM label placed out-of-band in terms of the payload channel), the transmission penalty is 0.7 dB, and at an EAM driving voltage of 50 mV ($\eta = 0.17$) the additional transmission penalty is only 1.1 dB. Therefore, the in-band subcarrier labeled signal can be generated and transmitted over a 80 km NZDSF span without inducing significant penalty on the 40 Gbit/s payload, thus demonstrating the feasibility of this labeling scheme.

4 Conclusion

We have experimentally demonstrated the feasibility of in-band SCM labeling of 40 Gbit/s DPSK payload for transmission over 80 km NZDSF. With a modulation depth of $\eta = 0.17$ the additional receiver penalty of the labeled signal over pure DPSK transmission is only 1.1 dB. We have shown that transmission is feasible operating at a subcarrier frequency of only 3 GHz, making the subcarrier label signal processing simple and cost effective.

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