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In-Band Time-to-Live Signaling System for Combined DPSK/SCM Scheme in OLS

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Abstract—We propose and validate experimentally a time-to-live (TTL) signaling system for an optical label swapping scheme based on 10-Gb/s differential phase-shift-keying (DPSK) packets and with 100-Mb/s subcarrier multiplexing (SCM) label. The proposed scheme allows fast packet discarding by using a 3-GHz subcarrier tone. DPSK payload has only a 2.4-dB power penalty at 10^{-9} bit-error rate after superimposing the SCM and TTL labeling signal.

Index Terms—Optical burst switching, optical communication, wavelength conversion, wavelength-division-multiplexing (WDM) networks.

I. INTRODUCTION

DUE TO THE continuing growth of the Internet and the introduction of high-bit-rate wavelength-division-multiplexing (WDM) connections in metro and backbone networks, the migration toward flexible switching solutions are becoming more apparent. One solution is optical label swapping (OLS), that enables the implementation of packet routing and forwarding functions in Internet-protocol-over-WDM [1]. By using short fixed-length labels, the core nodes of the network forward/switch packets fast and efficiently while keeping the payload data entirely in optical domain. Previous work has been done for label encoding for differential phase-shift-keying (DPSK) signal [2], [3]. However, our proposed labeling technique combines angles modulation and subcarrier multiplexing (SCM), namely the payload data is encoded in DPSK modulation format and the label information is transported by using SCM techniques. The robustness against chromatic dispersion, polarization-mode dispersion, and cross-phase modulation effects during transmission along optical fibers have been reported previously for this scheme [4], as well as record-high capacity and link reach optical transmission by using DPSK modulation format [5], [6].

OLS also offers the advantage of being protocol transparent, compatible with legacy and emerging network technologies by adopting the generalized multiprotocol label switching (GMPLS) frame work for a unified control plane. One problem faced by burst and packet switched networks is the "routing loops," where misdirected or mislabeled packets are routed in circles without reaching their destination [7], producing network congestion.
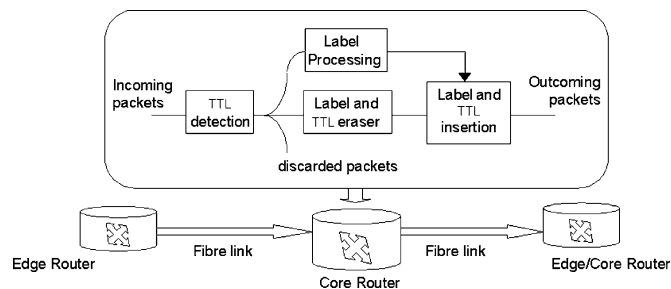
Fig. 1. Core router architecture with TTL signaling in a combined DPSK/SCM modulation format scheme.

To minimize this problem, MPLS and GMPLS [8], [9] incorporate a "time-to-live"(TTL) field that is decremented by one at each "hop" and when the values reaches zero, the packet is dropped from the network.

We propose and demonstrate experimentally an in-band signaling system by introducing the TTL value state (still-valid packet or discarded packet) in the optical domain, allowing fast recognition of the packet state in the node. If the packet is to be discarded, it will be dropped even before reading the label and so saving time node resources, compared to the broad-band wavelength systems proposed previously [10]. Our technique utilizes the DPSK modulation to convey the payload information. On the other hand, a SCM signal at 1 GHz is used for the label data and a sinusoidal tone at 3 GHz for the TTL state, as shown in Fig. 1. The label and TTL swapping is performed by using a semiconductor optical amplifier (SOA) as eraser.

II. OPERATION PRINCIPLE OF THE SOA AS OPTICAL LOW-PASS FILTER

The SOA is a suitable candidate for performance the label erasure due to its photonic integrability, low cost, and possibility of use as amplifiers. A rate equation model for an SOA with a carrier density that is uniform along the SOA length was developed in [11]. Afterwards, the equations were simplified in [12] by assuming that the effects of spontaneous emission and residual facet reflectivities are negligible. Gain through the SOA is given by a time-dependent solution which is simply an exponential function, characterized by a time constant called the effective recovery time of the carriers

$$\frac{1}{\tau_{\text{eff}}} = \frac{1}{\tau_e} - \frac{\gamma \Gamma a L \alpha_{\text{int}}}{A} \frac{P1}{hv1} \tag{1}$$

where τ_e represents the carrier lifetime, τ_{eff} is the effective recovery time of the carriers, A is the area of the SOAs active region, h is Planck's constant. P_1 and v_1 are the power (in watts)
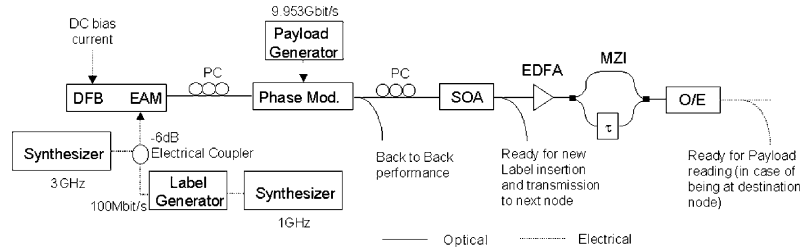
Fig. 2. Experimental setup. Using gain saturation in an SOA, the label and the TTL signal can be removed.

and the frequency, respectively, of the continuous-wave holding beam light. Γ is the length of the SOAs active region, a is the area and the length, respectively, of the SOA, α_{int} is the SOAs intrinsic losses.

This equation is mathematically verified and experimentally validated in [12].

Therefore, the gain response of the SOA will be determined by this τ_{eff}, being the cutoff frequency as follows:

$$f_c = \frac{1}{2\pi\tau_{\text{eff}}}. \tag{2}$$

From (2), we can deduct that varying the power injected to the SOA, the bandpass of the gain can be tuned, obtaining label eraser.

III. EXPERIMENT AND RESULTS

The experimental setup is shown in Fig. 2. A distributed feedback (DFB) laser source with an integrated electroabsorption modulator (EAM) is used for inserting a radio-frequency (RF) signal at 1 GHz with a $2^{23} - 1$ pseudorandom binary sequence (PRBS) signal at 100-Mb/s amplitude modulation and the sinusoidal tone at 3 GHz, with 50 mV$_{\text{RMS}}$ and 300 mV$_{\text{RMS}}$ respectively, onto the optical carrier operating at the 1555.37-nm wavelength. The DFB section is biased at 80 mA while the EAM section is reverse biased at 0.6 V. A LiNbO$_3$ phase modulator is used to impose DPSK modulation at 10 Gb/s using a $2^{31} - 1$ PRBS pattern.

The average output power of the phase modulator was -7.4 dBm, with no observed variation of this value if either the label and the TTL signal were present. After extracting the back-to-back performance, the power of the signal was adjusted to -3.5 dBm by varying the bias current of the DFB laser to 90 mA and then it was fed into the SOA. This adjustment was done in order to find the optimal point for gain saturation in the SOA, related to the equations explained at Section II. Fig. 3 shows the RF spectrum of the signal before the SOA and after the erasure process.

We employed a single photodetector receiver for DPSK detection. In Fig. 4, the eye diagrams of the recovered DPSK signal back-to-back and after the transmission over the SOA module are shown. We can observe that the introduction of the label and the TTL signal [Fig. 4(a) and (b)] produces a broadening of the "1" level, but it does not substantially affect the eye opening. After the erasure process, the eye diagram become noisy but it keeps open enough for free error detection. Fig. 5 shows the bit-error-rate (BER) curves obtained for the DPSK unlabeled
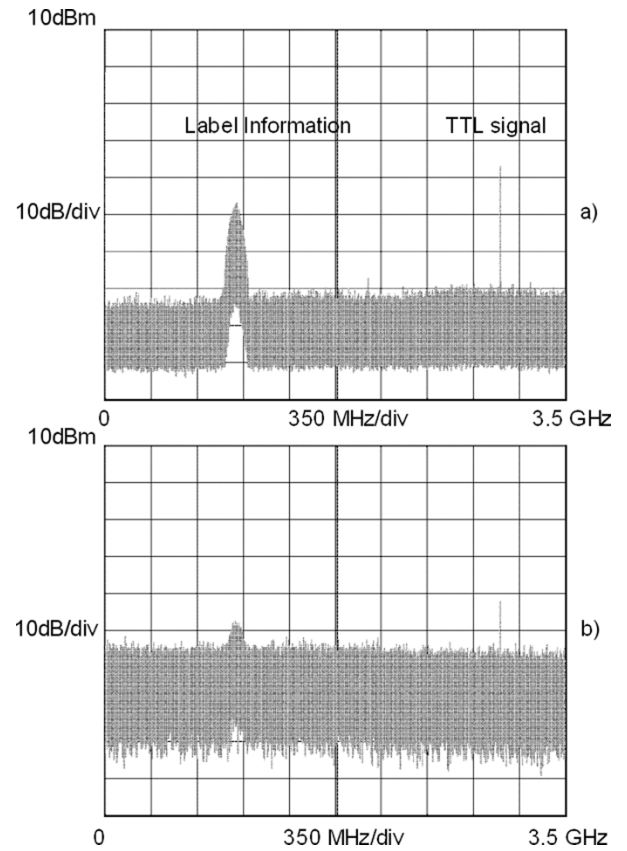

Fig. 3. RF spectrum of the original labeled and TTL signal (a) before the SOA and (b) after the erasure process.

and after the SOA (including with and without the label and the TTL signal).

The DPSK unlabeled receiver sensitivity was measured to be -26.9 dBm for a BER $< 10^{-9}$, and the combined effect of superimposing the label and the TTL signal introduces 2.4-dB penalty in total. For the DPSK signal after the erasure process, the received optical power level yielding a BER of 10^{-9} was measured to be -25.5. Therefore, only 1.4-dB penalty was suffered in the SCM and TTL erasure process. This power penalty might be reduced by using a balance receiver configuration and by proper optimization of the modulation index for the SCM and TTL signals to trade off SCM and DPSK performances.

In OLS networks, core nodes perform the functions of label reading and erasure, which we demonstrate in this letter. Label insertion and TTL signaling can be reinserted by using an EAM, similar to the one used in our experiment for label generation. Therefore, this architecture offers the prospect of integration on a photonic circuit.
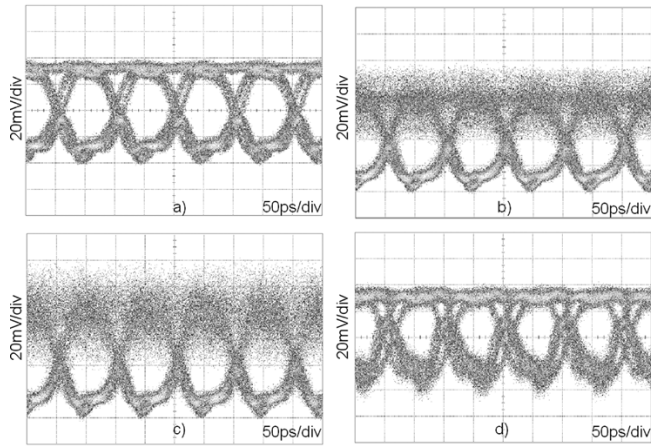
Fig. 4.   (a) Eye diagram of the DPSK signal alone, (b) with a label inserted, (c) with a label and a TTL signal inserted, and (d) after the erasure process in the SOA.
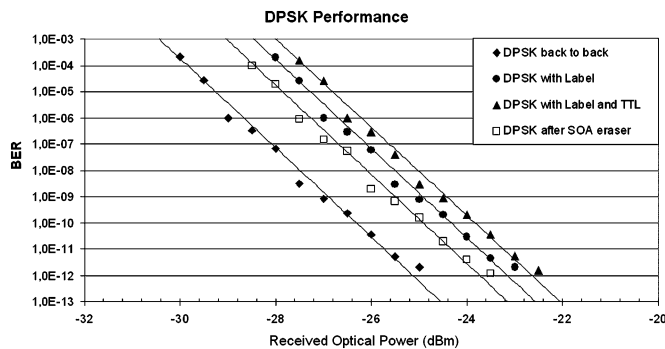

Fig. 5.   BER curves of the labeled and unlabeled DPSK signal, and the DPSK signal after the erasure process.

IV. CONCLUSION

We have presented an optical labeling switching technique based on the use of DPSK modulation for the high-rate payload data, SCM for the label information, and sinusoidal tone for the TTL signaling. We have experimentally demonstrated

its feasibility for 10-Gb/s DPSK 100-Mb/s SCM at 1-GHz label data and presence/no presence of tone at 3 GHz. We have analytically demonstrated the use of an SOA as low bandpass filter. The power penalty due to insertion of superimposed SCM and TTL signals is 2.4 dB. After the SCM and TTL erasure process, a power penalty of 1.4 dB was measured, compared to the back-to-back DPSK performance.

REFERENCES

[1] C. Qiao and Y. Chen, "The potentials of optical burst switching," in *Proc. Optical Fiber Communication (OFC)*, vol. 1, 2003, Paper TuJ5, pp. 219–220.

[2] N. Chi, C. Mikkelsen, L. Xu, J. F. Zhang, P. V. Holm-Nielsen, H. Ou, J. Seoane, C. Peucheret, and P. Jeppesen, "Transmission and label encoding/erasure of orthogonally labeled signal using 40 Gbit/s RZ-DPSK payload and 2.5 Gbit/s IM label," *Electron. Lett.*, vol. 39, no. 18, pp. 1335–1337, 2003.

[3] X. Liu, Y. Su, X. Wei, J. Leuthold, and R. C. Giles, "Optical-label switching based on DPSK/ASK modulation format with balanced detection for DPSK payload," in *Proc. Eur. Conf. Optical Communication (ECOC 2003)*, 2003, Paper Tu4.4.3.

[4] M. Rohde *et al.*, "Robustness of DPSK direct detection transmission format in standard fiber WDM systems," *Electron. Lett.*, vol. 36, no. 17, pp. 1483–1484, 2000.

[5] B. Zhu, L. E. Nelson, S. Stulz, A. H. Gnauck, C. Doerr, J. Leuthold, L. Grüner-Nielsen, M. O. Pedersen, J. Kim, and R. L. Lingle Jr, "High spectral density long-haul 40-Gb/s transmission using CSRZ-DPSK format," *J. Lightwave Technol.*, vol. 22, pp. 208–214, Jan. 2004.

[6] C. Rasmussen *et al.*, "DWDM 40G transmission over trans-pacific distance (10 000 km) using CSRZ-DPSK, enhanced FEC, and all-raman-amplified 100-km ultrawave fiber spans," *J. Lightwave Technol.*, vol. 22, pp. 203–207, Jan. 2004.

[7] V. Paxson, "End-to-end routing bahavior in the internet," *IEEE/ACM Trans. Networking*, vol. 5, pp. 601–615, Oct. 1997.

[8] L. Berger, "Generalized multi-protocol label switching (GMPLS) signaling functional description," RFC, Memo 3471, Jan. 2003.

[9] P. Agarwal and B. Akyol, "Time to live (TTL) processing in multi-protocol label switching (MPLS) networks," RFC, Memo 3443, Jan. 2003.

[10] J. E. McGeehan, S. Kumar, D. Gurkan, S. M. R. Motaghian, A. E. Willner, K. R. Parameswaran, M. M. Fejer, J. Bannister, and J. D. Touch, "All-optical decrementing of a packet's time-to-live (TTL) field and subsequent dropping of a zero-TTL packet," *J. Lightwave Technol.*, vol. 21, pp. 2746–2752, Nov. 2003.

[11] M. J. Adams, J. V. Collins, and I. D. Henning, *Proc. Inst. Elect. Eng. Part J*, vol. 132, no. 58, 1985.

[12] M. T. Hill, E. Tangdiongga, H. de Waardt, G. D. Khoe, and H. J. S. Dorren, "Carrier recovery time in semiconductor optical amplifiers that employ holding beams," *Opt. Lett.*, vol. 27, no. 18, pp. 1625–1627, 2002.