All Optical Switching and Label Swapping Using HNLF and SOAs for 40 Gb/s Spectrally Encoded Systems

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Abstract—**HNLF and nonlinear SOA components are used to perform all-optical self-switching and label swapping of spectrally label encoded 40 Gb/s signals. A Q-factor of >6 is obtained after self-switching and label swapping for 21 channels.**

Keywords- Semiconductor Optical Amplifier, Highly Nonlinear fiber, Coding, Networks

I. INTRODUCTION

Label swapping is an important function of future networks based on optical label switching [1]. Here, one or more labels are renewed or added in an intermediate node of a multi-hop switched network. The labels are used as headers to determine the forwarding path or for the management of other networking functions such as quality of service (QoS). Previously, spectral amplitude code (SAC) labels have been proposed for label switching since they have benefits such as fast label recognition and the potential for a large label set of codes [2]. A SAC label consists of wavelength tones with a code weight (wavelengths with high amplitudes or "1" and code length (total number of wavelengths). All optical label swapping has been demonstrated for SAC labels with weight 4 using a semiconductor ring laser for label swapping [2]. However, this system needs a bank of optical decoders to recognize the SAC labels and multi-wavelength conversion for label swapping since the SAC labels have weight > 2.To alleviate the use of a bank of correlators, multiple SAC labels can be recognized by a single correlator using four wave mixing (FWM) sideband (SB) allocation and selective optical filtering [3]. Label switching of signals with separate payload was demonstrated in [3]. Recently, a control-less fast self switching system that self-switches the signal to a FWM sideband according to its specific SAC have been demonstrated [4].

The approach here does not need switch fabrics or other complex items, such as complex de/encoders, short pulses, envelope detection, etc. In this paper, we demonstrate for the first time all-optical self switching with label swapping for the two-weight code self switching system using FWM and cross gain modulation (XGM) respectively. Since the codes are built with only two wavelengths, this alleviates the cost, power consumption and complexity of the label swapping section since multi-wavelength conversions for swapping one code to another are not necessary. Here, new bins are formed by converting the wavelength of the switched signal to a new bin via XGM whilst the second bin is a local cw signal to form the new label. A schematic of the self switched network with label swapping is shown in fig. 1.

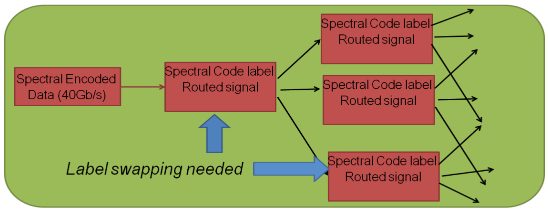

Fig.1. Multi-hop spectral coded label self switched network

II. OPERATIONAL PRINCIPLE AND EXPERIMENTAL SETUP

Fig. 2 shows the optical packet format. Each SAC label is modulated by the data payload. Thus, the label is implicit in the payload bits (each bit has two wavelengths) allowing the payload to be self-switched by FWM according to table 1 (which is developed using an algorithm similar to the one used for FWM long distance transmission [3]). The code family used has a length of 7, a weight of 2 and a total set of 21 codes. The bins are separated by a multiple of a frequency slot (Δf), in this case 100 GHz, which is also the minimum bin separation. The frequencies that overlap with others cannot be used for self-switching and these are highlighted in grey in table 1. It is important to notice that in [3], a nonlinear SOA was used and a shorter table was demonstrated since its FWM efficiency response less than the HLNF. The HNLF allows to have enough FWM reponse for about 15nm bandwidth. Figure 3 shows the experimental setup. Two tunable lasers, TL1 and TL2, generate the spectral code labels and they are modulated by the data, thus producing the spectrally encoded bits. As an example we use code 20 in table 1.

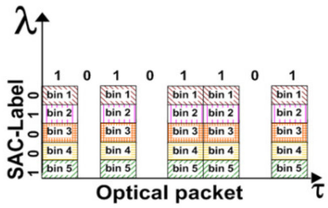

Fig.2. Optical packet format

TABLE 1. WAVELENGTH BIN ALLOCATION FOR SAC-LABEL FAMILIES

in nm	0	2	6	9	13	17	20	Δf=100GHz	
Code	1544.1	1545.7	1548.9	1551.3	1554.5	1557.8	1560.2	FWM 1	FWM 2
1	1	1	0	0	0	0	0	1547.32	1542.5
2	1	0	1	0	0	0	0	1539.37	1553.7
3	1	0	0	1	0	0	0	1537	1558.9
4	1	0	0	0	1	0	0	1533.86	1565.1
5	1	0	0	0	0	1	0	1530.72	1571.7
6	1	0	0	0	0	0	1	1528.38	1576.6
7	0	1	1	0	0	0	0	1542.54	1552.1
8	0	1	0	1	0	0	0	1540.16	1557
9	0	1	0	0	1	0	0	1537	1563.5
10	0	1	0	0	0	1	0	1533.86	1570
11	0	1	0	0	0	0	1	1531.51	1575
12	0	0	1	1	0	0	0	1546.52	1553.7
13	0	0	1	0	1	0	0	1543.33	1560.2
14	0	0	1	0	0	1	0	1540.16	1566.7
15	0	0	1	0	0	0	1	1537.79	1571.7
16	0	0	0	1	1	0	0	1548.11	1557.8
17	0	0	0	1	0	1	0	1544.92	1564.3
18	0	0	0	1	0	0	1	1542.54	1569.2
19	0	0	0	0	1	1	0	1551.32	1561
20	0	0	0	0	1	0	1	1548.91	1565.9
21	0	0	0	0	0	1	1	1555.34	1562.6

After 25 km of SMF transmission and the corresponding DCF, at the intermediate node we implement all optical self switching and label swapping.

Firstly, the 40Gb/s spectrally encoded signal is propagated through a highly nonlinear fibre (HNLF) where it is wavelength switched to only one FWM SB (output port) following table 1 - in this case to a wavelength of 1548.91 nm (port 20). The HNLF has a zero dispersion wavelength at 1552nm, a length of 135 m and a nonlinear coefficient of 20 $(W.km)^{-1}$. Suppose we desire to transmit to the next node identified by Code 19, we need to implement a label swapping section. This is achieved using two local lasers in the intermediate nodes (TL3 and TL4), and a SOA which has 15 dB gain and saturation power of 12 dBm. XGM in the SOA is used to convert the signal from 1548.91nm (incoming signal from Port 20) to 1554.54nm using TL3 (this signal becomes one bin of new Label 19). The cw signal from TL3 is transmitted in the counter propagation direction in the SOA so filtering of this signal is avoided after the XGM process.

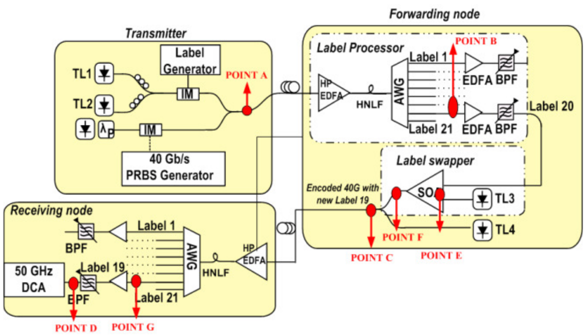

Fig.3. Experimental setup

After the self-switched data signal has been converted, it is combined with TL4, which provides the second bin of the new SAC label. To build label 19, it is tuned to 1557.8 nm. At the receiver node, the Code label 19 is self routed to Port 19 and its Q factor is measured using a 50 GHz digital communications analyser (DCA).

III. RESULTS AND DISCUSSION

Figures 4(a) to 4(d) show the eye diagrams of the 40 Gb/s signal at different stages in the system (the stages are labelled in Fig. 3). Fig 4(a) shows the transmitted eye of the original label code 20 which has with Q-factor of 10.1 (point A in the setup). Fig. 4(b) shows the eye diagram of the Code 20 after FWM self switching, with Q=7.33 (point B). Fig. 4(c) and 4(d) show the wavelength routed signals converted from 1548.91 nm to 1554.54 nm, with Q factors of 6.5 and 6.02, respectively (points C and D). Fig. 4(e) to Fig 4(h) show the spectrum of the signal at the corresponding stages. Fig. 4(e) shows the Code 20 spectrum after FWM at the intermediate node (point B), where we can see the input bins and the two SBs. The SB at 1548.91nm is filtered and input to the swapping processor. Fig. 4(f) shows the incoming Code 20 data together with the CW signal used in the XGM wavelength conversion process (point E). It should be noted that the data is inverted from the original. The signal after wavelength conversion and filtering is shown in Fig 4(g) (point F). Finally, the spectrum of the 40 Gb/s signal encoded with the new Code 19 is shown in Fig 4(h) (point G).

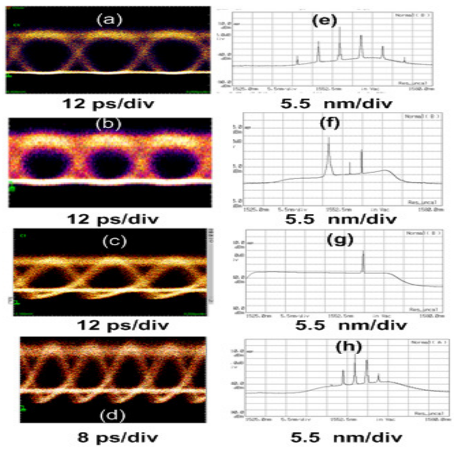

Fig. 4. (a) Original eye diagram of the 40 Gb/s Code 20 spectrally encoded data; (b) 40 Gb/s encoded signal after self routing by FWM; (c) 40 Gb/s encoded signal after wavelength conversion by XGM; (d) 40 Gb/s encoded signal with Code 19 after self routed by FWM; (e) Spectrum of Code 20 after FWM in the forwarding node; (f) spectrum of filtered 40 Gb/s signal and the CW used in the XGM process; (g) converted 40Gb/s data (h) 40Gb/s coded signals after FWM at the receiver.

IV. CONCLUSIONS

We have demonstrated for the first time a self switching system based on two weight codes and FWM in a HNLF with long bandwidth response. Furthermore, it is demonstrated all optical label swapping of spectrally label encoded 40 Gb/s signals is optimized using XGM in a nonlinear SOA for a 21-port self routing system. In contrast to previous SAC label swapping demonstrations, multi-wavelength conversion is not needed. A Q-factor of >6 is obtained after self-switching by FWM and label swapping. It is possible to route 21 different 40 Gb/s signals in a multi-hop self switched label system with a total throughput of 0.84 Tb/s.

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