SCM optical label switching scheme in a WDM packet transmitter employing a switching SG-DBR laser

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Abstract: We demonstrate an SCM optical label switching scheme with spectral efficiency of 0.4bit/s/Hz and a spectral density figure of merit of 1. We then employ this scheme in a WDM transmitter subsystem and we investigate the detrimental effects that switching events in tunable lasers can have on such systems. The label performance is shown to hit an error floor when the tunable laser switches channels and this would cause incorrect routing of packets. The bit error rate is time resolved in order to better understand the problem and some possible solutions are discussed.

Keywords: Optical Label Switching, Optical Packet Switching, Tunable Laser, Subcarrier Multiplexing

1. Introduction

Optical label switching (OLS) is a technique which has been proposed to simplify the routing process in an optical packet switching (OPS) network and it seems likely that it will be employed when OPS is commercially deployed. In conventional OPS, the packet payload and header would be transmitted at the same data rate, which, as data rates continue to rise, could lead to a bottleneck in the routing process. The use of a label which is simpler and smaller than the packet header, to route the data through the network, allows it to be transmitted at a slower data rate and still arrive within the same time slot. This allows the routing information to be processed in the electrical domain, cheaply and quickly while the payload remains in optical format in some form of delay line. Once the routing decision is made the packet is forwarded in the direction of it’s destination.

A number of methods for coding labels have been proposed. Examples include bit serial, orthogonal and subcarrier labelling [1,2]. In this paper we consider subcarrier multiplexed (SCM) labels which are generated by mixing the label data signal with an RF local oscillator. The label can then be multiplexed with the payload optically [3], electrically [4] or opto-electrically [5].

SCM labels have the advantages that they are easily generated thanks to the readily available and inexpensive RF components. Label extraction and detection is also simple using an optical band pass filter and direct detection removing the need for down-conversion at each node. Disadvantages associated with SCM labelling include it’s susceptibility to dispersion induced fading and intermodulation distortions due to system nonlinearities. Also because the label generally lies out of band, this method is less spectrally efficient than bit serial or orthogonal labelling for example. Nevertheless, in section 2 of this paper we demonstrate an SCM labelling method which combines good spectral efficiency (0.4bit/s/Hz) and good spectral density figure of merit (1) with low crosstalk between payload and labels. In our scheme we use a 42.6Gbit/s duobinary payload and a 2.5Gbit/s NRZ label which sits on a 42.6GHz subcarrier.

The majority of optical labelling schemes in the literature concentrate on single channel systems when in practice OPS systems will have multiple WDM packets transmitted simultaneously side by side. The packet transmitters in the edge nodes of the label switched network will contain fast tunable lasers, which will switch wavelength on a packet by packet basis, depending on the destination of each packet. In section 3 we use the labelling scheme detailed in section 2 to create a multi-channel system which takes into account the switching of these tunable lasers and we discuss the issues which may be encountered.

2. Experimental Work 1

The initial experimental setup is shown in Figure 1. The transmitter consisted of a tuneable SG-DBR laser [6] (TLS), and a Mach-Zehnder modulator (MZM). The modulator drive signal consisted of the SCM label signal (which was produced by modulating a baseband 2.5 Gb/s NRZ label onto a 42.6 GHz clock using an RF mixer) combined with the duobinary payload (which was generated by passing a 42.6 Gb/s pre-coded NRZ of 50% duty cycle through a duobinary amplifier) To obtain optical carrier suppression of more than 15 dB, the MZM was biased at the minimal intensity-output point. The optical spectra of the transmitted and received payload and labels are shown in Figure 1. The use of a single modulator for both payload and label ensures that a subcarrier signal is always present, albeit somewhat amplitude modulated by the payload data.

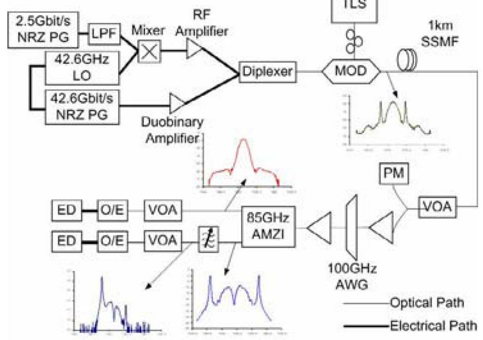

Figure 1: Transmitter and receiver for subcarrier multiplexed payload and label.

The signal was then passed into the receiver where a 100 GHz flat-top arrayed waveguide grating (AWG) was used to remove amplified spontaneous emission (ASE) introduced by the optical amplifier. By passing the signal through an asymmetric Mach Zehnder Interferometer (AMZI) with a free spectral range (FSR) 85.2 GHz the payload was suppressed on one port and the double sideband (DSB) labels suppressed on the other. The label information was then extracted using a tunable Fabry Perot filter with a bandwidth of 6.25 GHz.

Figure 2a shows the performance of the payload with and without the labels and figure 2b shows the performance of the labels with and without the payload, both after passing through 1km of standard single mode fibre (SSMF). In figure 2a, the payload pattern length was 2^7-1. It can be seen that the addition of the label barely affected the receiver sensitivity of the payload, introducing a power penalty of <1 dB. Also, there was no observable power penalty for the payload receiver sensitivity for different label pattern lengths. Whilst figure 2(b) illustrates a change in total received power for a 10^-9 error rate of 11dB, over 8dB of this results from the reduction in the fraction of the power of the transmitted signal, and in terms of the received label power alone, a power penalty of less than 3dB is observed for a 2^7-1 payload. In addition to this, as the payload pattern length was increased, the penalty increased by up to 1.8dB.

We have also shown that by reducing the gain of the duobinary amplifier by -1.2dB, it was possible to achieve the same receiver sensitivity (approx -27dBm) for both payload and label [7].

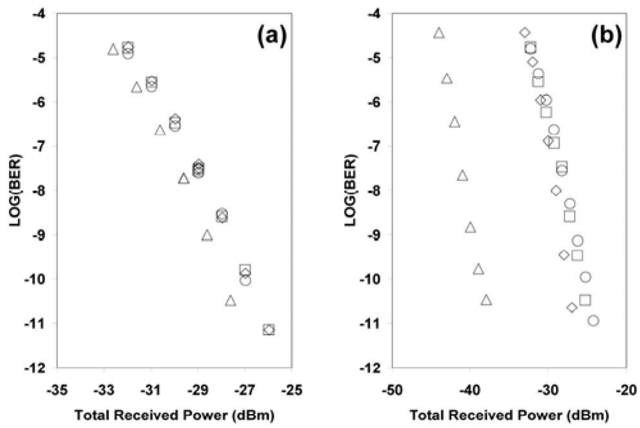

Figure 2: BER versus received power for: a) payload PRBS 2^7-1 without labels (△); with 2^7-1 labels (◇); with 2^{15}-1 labels (□); with 2^{31}-1 labels (O) b) labels of PRBS 2^7-1 without payload (△); with 2^7-1 payload (◇); with 2^{15}-1 payload (□); with 2^{31}-1 payload (O)

3. Experimental Work 2

We then went on to examine the performance of the payload and label in a multi-channel system with a tunable laser switching between different wavelength channels. The experimental setup is basically an extended version of the previous one and is shown in figure 3.

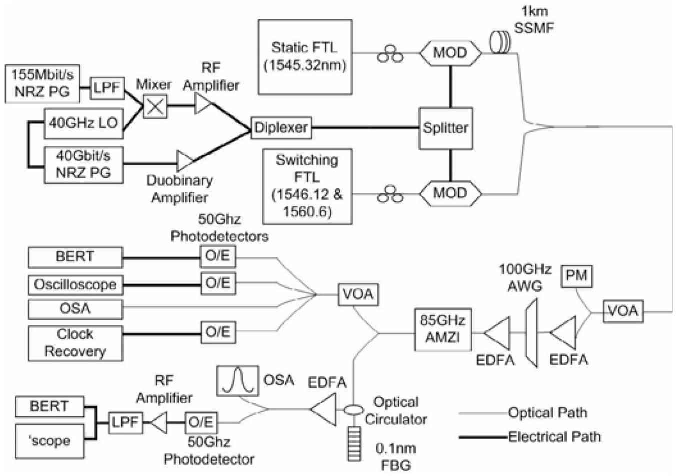

Fig. 3. Experimental setup employing two fast tuneable lasers

Two SG-DBR laser transmitters are modulated with a data signal which consists of 40Gbit/s duobinary baseband data combined with a 40GHz subcarrier modulated with a label at 155 Mbit/s. The reason for the change in label data rate was equipment limitation. The payload drive voltage to each modulator is approximately 0.9 $V\pi$. The peak to peak drive amplitude of the subcarrier is less than 0.5 $V\pi$. One of the channels is then passed through 1km of SSMF in order to decorrelate the data patterns and then the two channels are coupled together.

The signal is pre-amplified and one channel is selected using a 100 GHz flat-top profiled arrayed waveguide grating (AWG) with a 3dB bandwidth of 65GHz. A second EDFA is then used to boost the signal before filtering it with an AMZI as before to separate the label and payload.

In the label receiver, a Fiber Bragg Grating (FBG) with a 3 dB reflection bandwidth of approximately 12 GHz is used to extract one of the label sidebands. This bandwidth is wide enough to allow for wavelength drift of the tuneable laser. The reflected label is directly detected using a square law detector and then the electrical signal is amplified, low pass filtered, split and passed into the bit error rate tester (BERT) and oscilloscope.

Initially we took the same set of results for the modified experiment (not presented here). As expected we saw that the presence of the label hardly affects the payload at all. However, the presence of the duobinary payload has a large effect on the label introducing a power penalty of approximately 13dB. Of this label penalty, 11.4 dB is attributable to the power distribution between the payload (93%) and label (7%). The remaining 1.6 dB penalty is attributed to the aggregate modulation of the bias position of the 40 GHz sub carrier by the payload data (averaged over 258 bits).

Figure 4a shows the performance of the payload in 3 different circumstances. The first case is with just a single channel. The second case is with two channels 100GHz apart but without any switching of the fast tunable laser. The final case is when the channel being measured is static and the other is switching from the adjacent channel to a distant channel every 260ns. The laser output is blanked using an SOA at the output of the laser for the first

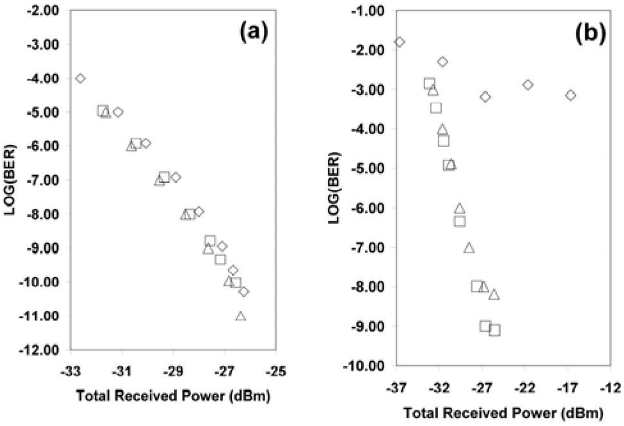

Fig.4. (a) Bit error rate of the 194 THz channel payload versus received power in one channel for 3 cases: single channel (△); two static channels (□); two switching channels (◇). (b) Bit error rate of the 194 THz channel label versus received power in one channel for 3 cases: single channel (△); two static channels (□); two switching channels (◇).

60ns of this time. After coming out of blanking the laser is always within ±12.5 GHz of it's target frequency. A wavelength locking circuit is then activated which holds the output within ±2.5GHz of the target channel after a maximum delay of 200ns after blanking. The addition of the second channel leads to a power penalty of approximately 0.5 dB due to inter-channel crosstalk. Further degradation due to the switching of the adjacent channel is negligible. This is the expected behaviour because of the wide spacing between the payloads in comparison to any drift of the tuneable laser that may occur.

Fig 4b shows the performance of the label in the same 3 circumstances: single channel, 2 static channels and two switching channels. Again the presence of an adjacent channel introduces very little penalty. However, when one of the lasers is switching, an error floor around 5×10^{-4} is introduced due to the label of the switching laser, entering the filter passband of the measured label. This is caused by the wavelength drift of the tuneable laser around its target wavelength.

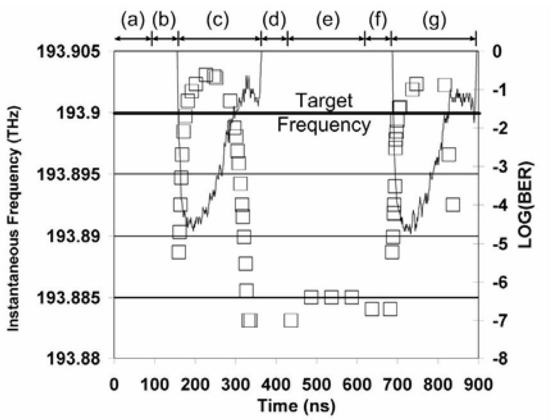

Fig. 5 Time Resolved Bit error rate measurements (□) and instantaneous frequency of the switching laser. The received power was approximately -28.5 dBm (a) laser at freq 194 THz, (b) laser blanked for 60ns, (c) laser settling into freq 193.9 THz for 200ns, (d) laser blanked for 60ns, (e) laser at freq 194 THz for 200ns, (f) laser blanked for 60ns, (g) laser settling into freq 193.9 THz for 200ns

In figure 5 we show the instantaneous frequency of the switching laser (extracted from complimentary outputs of the 85GHz AMZI biased at quadrature for the target frequency) and overlay it with the time resolved bit error rate measurements (8ns gating interval) with a received power of -28.5 dBm. A direct correlation can be seen between the wavelength drift after switching events in the tuneable laser and the time intervals when there are significant errors on the received label data. While the laser is blanked and also while it sits at the distant channel, the error rate drops considerably. However as the laser tunes towards and begins settling on it's target channel the error rate increases dramatically.

4. Conclusion

We have demonstrated a novel spectrally efficient scheme for the labelling of optical packets. We observed that while the label did not cause much distortion of the payload signal, the payload introduced a power penalty of approximately 11dB. The majority of this penalty is due to power distribution. We then used this labelling scheme in a WDM system which employed a switching SG-DBR laser and examined the interference between adjacent labels which occurred as the laser attempted to settle into it's target wavelength. An error floor was shown to appear as a result of this interference and this would cause packets to be incorrectly routed. Clearly the error floor could be minimised by increasing the blanking time and/or channel spacing, with associated reduction in network throughput. More attractive solutions however include optimised label filter profiles, single side band sub carrier generation, and optimisation of the transient laser dynamics including operation of wavelength locking technique during the existing blanking period.

5. Acknowledgments

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6. References

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