Spectrally Compact Optical Subcarrier Multiplexing with 42.6 Gbit/s AM-PSK Payload and 2.5Gbit/s NRZ Labels

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Abstract: A novel approach to optical subcarrier multiplexing with compact spectrum is demonstrated using a 42.6 Gbit/s AM-PSK payload and 2.5 Gbit/s NRZ label. The payload introduces 4.8 dB implementation penalty on labels sensitivity and the label causes <1 dB penalty on the payload receiver sensitivity.

Introduction: Label controlled switching is a promising technique for optical packet routing over high bit rate wavelength division multiplexed networks, eliminating the need for digital circuits operating at the payload data rate. A number of methods of coding labels have been proposed, for either label swapping or deterministic routing algorithms [1-5]. Depending on the particular implementation, the overall system performance is impacted in various ways: by reducing the overall spectral efficiency [2]; by reducing the payload extinction ratio to allow sub-carrier modulation [3]; or by introducing sophisticated transmitter [4] or receiver configurations to perform label erasure and reinsertion [5].

In this paper, we propose and demonstrate a novel scheme for deterministic optical subcarrier labelling to enable spectrally compact label controlled switching with low system penalty. Our proposed scheme uses a single MZ modulator with combined electrical drive signals to generate simultaneously an AM-PSK payload and a NRZ sub-carrier multiplexed label. This offers a compact spectrum compatible with using a 40 Gbit/s payload on 100 GHz channel spacing, with very low crosstalk between the payload and labels. This results in excellent receiver sensitivities, and requires 10 dB less optical power in the payload compared to OCSS [4]. The low crosstalk allows the use of a high data rate (2.5 Gbit/s) label, ensuring good address scalability when using a deterministic routing algorithm. It is also anticipated that the AM-PSK payload will offer additional advantages, including high dispersion tolerance.

Experimental setup: The experimental arrangement is illustrated in figure 1. The subcarrier-multiplexed transmitter consisted of a tuneable sampled-grating DBR laser (TLS), a Mach-Zehnder modulator (MZM) and an electrically subcarrier-multiplexed drive signal. For this work, the laser wavelength was fixed (1545 nm). A spectrally compact payload was generated by using various pseudorandom binary sequences (PRBS) followed by a duobinary amplifier. The compact spectrum allows a closely spaced subcarrier signal to be used. This subcarrier-multiplexed signal was produced by modulating a baseband 2.5 Gbit/s NRZ label onto a 42.6 GHz clock (which was synchronised to the data signal) using a RF mixer, and passively combining this signal with the duobinary payload in the electrical domain using a diplexer.

Note that for both signals, optimum performance was obtained with the MZM biased at the point of minimum output intensity, in order to generate an AM-PSK signal from the duobinary payload drive, and a carrier suppressed signal with extinction of the label at the optical carrier frequency in excess of 15 dB. The drive amplitudes of the payload and label were optimised to minimise crosstalk, and ensure a minimum optical power in each sideband label to be 6% of the total transmitted optical power. This corresponded to drive signal amplitudes of approximately $V\pi$ for the payload and 0.7 $V\pi$ for the label. The optical spectra of the transmitted and received payload and labels are shown in figure 2.

At the receiver, the signal power was monitored using a power meter and an optical spectrum analyser, allowing the individual power levels of the payload and labels to be determined. The signal was then optically pre-amplified before passing through a flat-top arrayed waveguide grating (AWG) with 100 GHz ITU channel spacing to remove amplified spontaneous emission from the optical amplifier. The payload and double sideband subcarrier labels were separated in the optical domain using an asymmetric Mach-Zehnder interferometer (AMZI) with an 85.2 GHz free spectral range. Additional filtering of the label with a Fabry-Perot filter of 6.25 GHz bandwidth selected either the upper or lower sideband, thus simultaneously allowing direct detection with a receiver optimised for the label bit rate and eliminating any dispersion-induced carrier fading [6] due to fibre transmission (although this was not an issue in our experiment, since only 1 km fiber were used). This filter also minimised any spectral interference between the residual payload and label.

Results: In figure 3a, we compare the receiver sensitivities of a 2^7-1 PRBS payload only and when both this payload and labels of various PRBS lengths were generated. It can be seen that adding the label introduced small power penalty of <1 dB, irrespective of the label length. The low pattern sensitivity is to be expected, since each payload bit will experience the same penalty for either a 1 or 0 bit in the label. We anticipate that this penalty will be further reduced if the relative phases of the 42.6 GHz subcarrier and 42.6 Gbit/s payload signal are aligned.

However, as shown in figure. 3(b), the presence of the AM-PSK payload introduced 3 dB label sensitivity power penalty (2^7-1 label sequence). In this case, since each label bit is impacted by up to 16 payload bits, the effective bias point for the subcarrier signal may be modulated by the low frequency content of the payload data, increasing the penalty by 1.8 dB as the payload sequence length was increased from 2^7-1 to 2^{31}-1. For a duobinary drive amplitude of $V\pi$, we would expect this effect to induce a maximum amplitude modulation of the subcarrier signal of 3dB.

Figure 4a shows the system performance in terms of the required total (payload plus labels) received power at BER of 10^{-9} performance as a function of the relative gain of the duobinary amplifier. Whilst this directly determines the power of the AM-PSK signal, and consequently the relative power of the subcarrier label, only a slight variation in the payload extinction ratio penalty is expected. By controlling the relative power levels in this way it is possible either to achieve BER of 10^{-9} for payload and labels at same total received power, or to favour the label signal, thus minimising packet loss. Figure 4b shows receiver sensitivities of labels versus label PRBS length, with and without a payload of various PRBS lengths. This confirms that the label penalty is determined only by the payload sequence length.

Conclusions: We have demonstrated a novel, spectrally compact, subcarrier-labelling scheme with a 42.6 Gbit/s duobinary payload and 2.5 Gbit/s labels. In this scheme, the label introduces a pattern-independent penalty of <1 dB on the payload receiver sensitivity and the payload causes a pattern dependant penalty of up to 4.8 dB on the label receiver sensitivity. The payload requires 10 dB lower optical power than for the OCSS scheme of ref. [4] and is compatible with operation using a 100 GHz WDM channel plan.

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Figure captions:

Fig. 1 Transmitter and receiver for subcarrier multiplexed payload and label

Fig. 2 Optical Spectra for: a) Transmitted subcarrier-multiplexed signal; b) Filtered Payload; c) Filtered double side bands label; d) Filtered single side band Label

Fig. 3 BER versus received power for: a) payload PRBS 2^7-1 with and without various labels; b) labels of PRBS 2^7-1 with and without various payloads, where Pm = payload with PRBS 2^m-1, Ln = label with PRBS 2^n-1

Fig. 4a) Total received power at BER 10^{-9} vs. reduction in gain of duobinary amplifier with and without labels/payloads. b) Receiver sensitivity of label as a function of PRBS length of label with and without payload. (Pn = payload with PRBS 2^n-1)

Figure 1

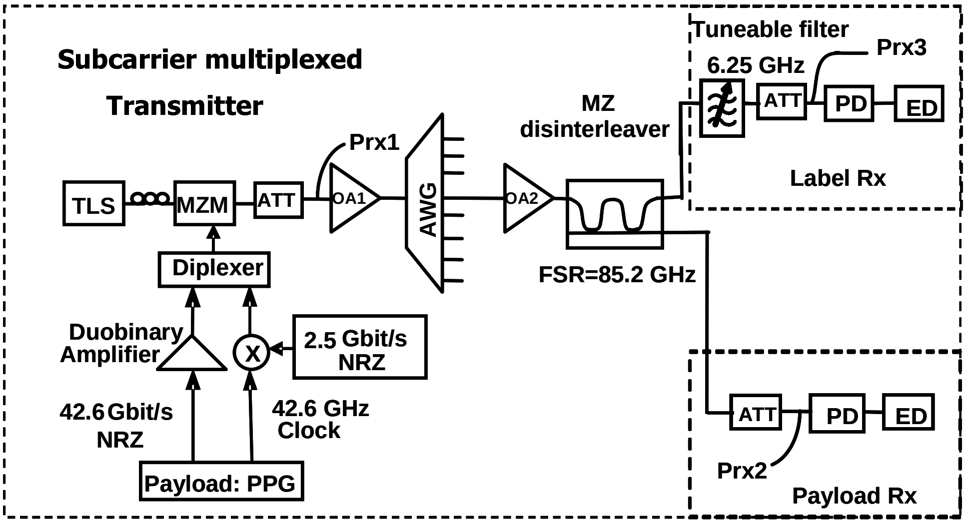
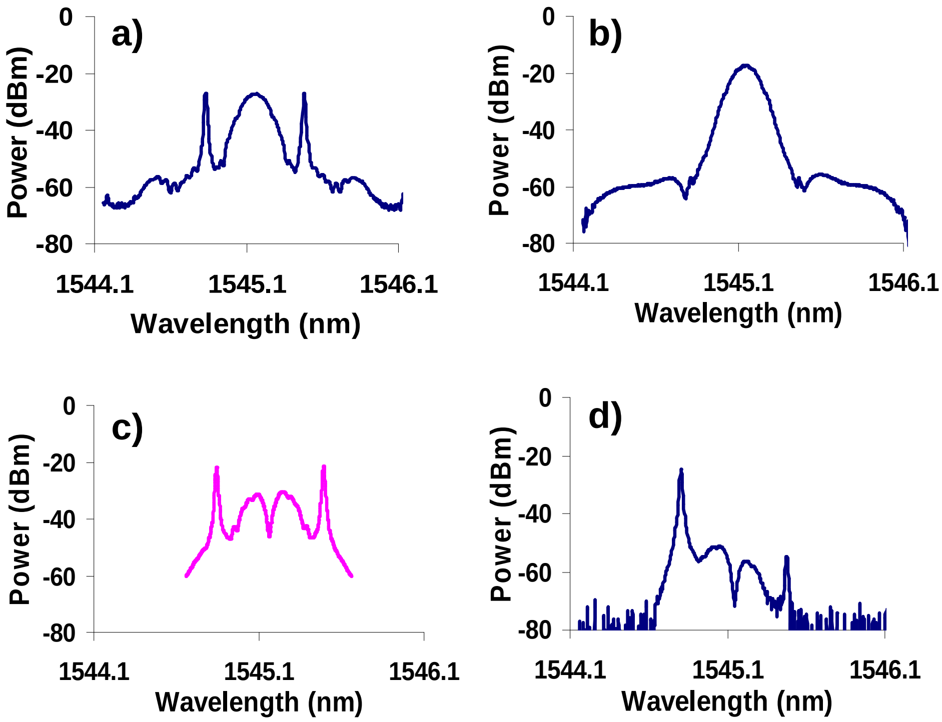

Subcarrier multiplexed
Transmitter
TLS
MZM
ATT
Prx1
OA1
AWG
OA2
MZ
disinterleaver
FSR=85.2 GHz
Diplexer
Duobinary
Amplifier
X
2.5 Gbit/s
NRZ
42.6 Gbit/s
NRZ
42.6 GHz
Clock
Payload: PPG
Tuneable filter
6.25 GHz
ATT
Prx3
PD
ED
Label Rx
ATT
PD
ED
Prx2
Payload Rx

Figure 2



a)
Power (dBm)
0
-20
-40
-60
-80
1544.1
1545.1
1546.1
Wavelength (nm)
b)
Power (dBm)
0
-20
-40
-60
-80
1544.1
1545.1
1546.1
Wavelength (nm)
c)
Power (dBm)
0
-20
-40
-60
-80
1544.1
1545.1
1546.1
Wavelength (nm)
d)
Power (dBm)
0
-20
-40
-60
-80
1544.1
1545.1
1546.1
Wavelength (nm)

Figure 3

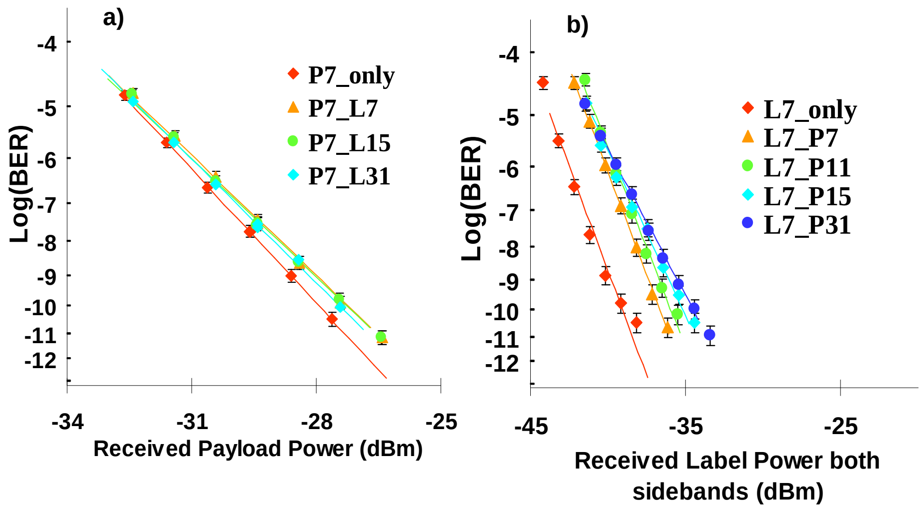
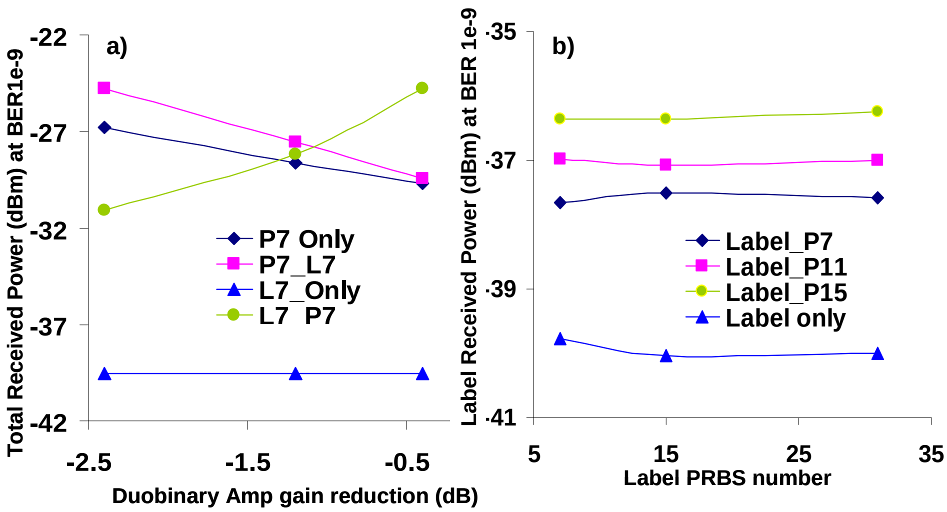

a)
Log(BER)
-4
-5
-6
-7
-8
-9
-10
-11
-12
P7_only
P7_L7
P7_L15
P7_L31
-34
-31
-28
-25
Received Payload Power (dBm)
b)
Log(BER)
-4
-5
-6
-7
-8
-9
-10
-11
-12
L7_only
L7_P7
L7_P11
L7_P15
L7_P31
-45
-35
-25
Received Label Power both sidebands (dBm)

Figure 4


a)
-22
-27
-32
-37
-42
-2.5
-1.5
-0.5
Total Received Power (dBm) at BER1e-9
Duobinary Amp gain reduction (dB)
P7 Only
P7_L7
L7_Only
L7_P7
b)
-35
-37
-39
-41
5
15
25
35
Label Received Power (dBm) at BER 1e-9
Label PRBS number
Label_P7
Label_P11
Label_P15
Label only