Fast Switching Burst Mode Receiver in a 24-Channel 112Gb/s DP-QPSK WDM System with 240km Transmission

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Abstract: We demonstrate the performance of a fast switching (< 150ns) 112Gb/s DP-QPSK digital burst mode coherent receiver in a 24-channel WDM system. A penalty of 0.5dB is experienced after propagating over 240km of SSMF.
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1. Introduction

The combination of higher order spectrally efficient modulation formats, coherent reception and digital signal processing has provided the platform to dramatically increase the transmission capacity of current lightwave communication systems. Digital coherent reception also provides numerous advantages such as frequency selectivity, high receiver sensitivity and the ability to compensate transmission impairments such as chromatic dispersion (CD) and polarization mode dispersion (PMD) through the use of adaptive linear digital filters [1]. The frequency selectivity associated with coherent reception offers significant potential to dynamic mesh or ring optical networks that utilize burst or packet switching, as rapid bandwidth provisioning can be achieved on demand with sub-wavelength granularity. In such network architectures, wavelength selectivity is provided by a widely tunable local oscillator (LO) in the coherent receiver, which can be dynamically reconfigured to drop the desired WDM channel at an intermediate node in the network [2]. Fast switching coherent burst mode receivers significantly reduce the number transponders required within each network node and also easily performs bypass of through optical channels, thus avoiding expensive OEO conversion and electrical processing.

However several key components are required in order to realize a practical implementation of a fast switching coherent burst mode receiver. Firstly the local oscillator must consist of a low phase noise, widely tunable semiconductor laser that is capable of switching to any ITU channel in the conventional wavelength band within 200 ns, thus achieving fast dynamic reconfiguration of the tunable receiver. Secondly, efficient parallelized digital signal processing algorithms are required to demodulate higher order modulation formats such as dual polarization quadrature phase shift keying (DP-QPSK) and also to compensate transmission impairments. Parallelized DSP algorithms are required for practical implementation on current application specific integrated circuits (ASIC).

Recent work on fast tuning coherent burst mode receivers has shown fast burst acquisition (within 200ns) [3], the use of a burst header to reduce the convergence time [4] and further increases the spectral efficiency through higher order modulation formats [5]. We have previously demonstrated a physically realizable parallel DSP implementation for the blind recovery of 112Gb/s DP-QPSK bursts, where the DSP used a 128 bit wide bus that is suitable for realization on an ASIC with a 437.5MHz clock speed [6]. In this paper we demonstrate the performance of the burst mode receiver, which utilizes a commercially available widely tunable semiconductor laser, in a 24-channel 112Gb/s DP-QPSK transmission test bed. The tunable laser dynamically switches between eight 50 GHz spaced channels after the WDM signal is transmitted over 240 km of standard single mode fiber.

2. WDM Transmission Test Bed

The 24-channel 112 Gb/s DP-QPSK WDM transmission test bed used in this work is illustrated in Fig. 1. The WDM transmitter consisted of two 100 GHz spaced banks of distributed feedback lasers (DFB) with linewidths varying from 0.6-2 MHz. Sixteen odd channels, ranging from 192.3-193.8 THz on the ITU grid, were bulk modulated with a decorrelated 28 Gbaud QPSK signal, which was derived from two interleaved 14 Gb/s 2^{15}-1 PRBS data streams. A bank of eight even WDM channels, ranging from 192.75-193.45 THz, was separately modulated using a second IQ modulator and decorrelated 28 Gbaud QPSK signal. The odd and even channels were subsequently polarization multiplexed to create a per channel data rate of 112 Gb/s before they were combined using an interleaver with a free spectral range of 50 GHz. This produced sixteen 50 GHz spaced WDM channels with four 100 GHz spaced channels at either end of the WDM signal. The transmission line consisted of three 80 km spools of standard signal mode fiber with a dispersion of 16.8 ps.nm/km at 1554 nm. Each fiber spool was followed by an erbium doped fiber amplifier (EDFA), which provided a launch power of approximately -2 dBm per channel. The 24-channel WDM signal, recorded after the transmission line, is displayed as an inset of Fig. 1. The power variation across the central sixteen 50 GHz spaced channels was 1.5 dB. An optical noise loading stage was used to vary the optical signal to noise ratio (OSNR) before the coherent receiver.

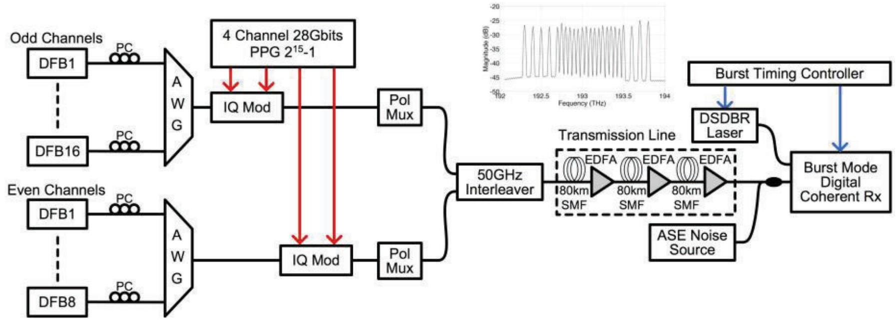

Fig. 1. Fast switching burst mode coherent receiver experimental setup.

The local oscillator in the coherent burst mode receiver was a commercially available digital supermode distributed Bragg reflector (DSDBR) tunable laser from Oclaro, which may be tuned to any 50 GHz channel on the ITU grid within 200 ns and provides an output power of 12 dBm [7]. The gain, SOA and one of the front mirror sections were biased at 150, 100 and 5 mA respectively. Wavelength switching was achieved by applying a series of 8 voltage steps, each with duration of 5μs, to the rear Bragg section and a second front mirror section using an arbitrary waveform generator (AWG), which simultaneously controlled the burst acquisition timing. This resulted in the TL switching across the 8 central WDM channels (193-193.35THz) sequentially before jumping back to the first channel. The side mode suppression ratio for each channel was greater than 45 dB. The laser phase tuning section remained unbiased and the linewidth of each channel was characterized using a time domain frequency estimation technique [8]. The linewidth ranged from 0.6 MHz for the 193.350 THz channel and monotonically increased to 1.8MHz for the 193.0 THz channel.

The optical signals were subsequently detected in a polarization diverse optical hybrid with balanced photodetectors and digitally sampled at 50 GS/s using a Tektronix oscilloscope that had a hardware bandwidth of 16 GHz. All 8 bursts were captured simultaneously and the parallel digital signal processing implementation was performed offline using Matlab. The digitized signals are first resampled to two samples per symbol and then mapped on to a 256 bit wide bus after which all processing is carried out on the 256 bit blocks in parallel. Firstly the dispersion is digitally compensated within the parallel 256 bit wide bus DSP implementation. To ensure fast convergence and avoid the degenerate condition the MIMO equalizer parameters are initialized using an estimator based on the constant modulus algorithm (CMA) error slope [6]. Following this the MIMO equalizer is updated once per block using the CMA, with a Gaussian window, where the central tap has an update parameter of μ=1.

3. Experimental Results and Discussion

The performance of the coherent burst mode receiver under wavelength switched operation after transmission over 240 km of SMF, is shown in fig. 2. The results from the eight recovered bursts that were captured on a single oscilloscope trace are overlaid on each other, when the input OSNR was 16.5 dB. The estimated frequency offset, shown in fig. 2(a), shows that there is a drift in the initial frequency of up to 1 GHz before reaching the steady state value after around 100 ns, particularly for the 193.0 THz channel which occurs due to the larger drive current variation when the LO is switched from 193.350 to 193.0 THz. The BER, in fig.2 (c), shows significant errors as a result of cycle slips. These arise when the phase estimation algorithm is unable to track the variations in the phase between the LO and the transmitter lasers. The problem of cycle slips can be avoided by using differential decoding, whereby the data is encoded in the difference in phase between adjacent symbols, and the decoding is done by simply considering the phase difference between the adjacent symbols after the frequency offset is removed. The CMA error and the differentially decoded BER, shown in fig. 2(b & d) respectively, are observed to converge within 150 ns.

The differentially decoded BER performance of the burst receiver as a function of the received OSNR is shown in fig. 3 for both the back-to-back (a) and after transmission over 240 km of SMF (b). The back-to-back BER shows an implementation penalty of 2 to 3 dB for the best and worst channels, respectively and after transmission the penalty is increased by 0.5 dB. The variation in the penalty across the channels arises mainly from the variation in the linewidth obtained at the different operating points of the DSDBR laser, where the worst performing channels correspond to the largest LO linewidth.

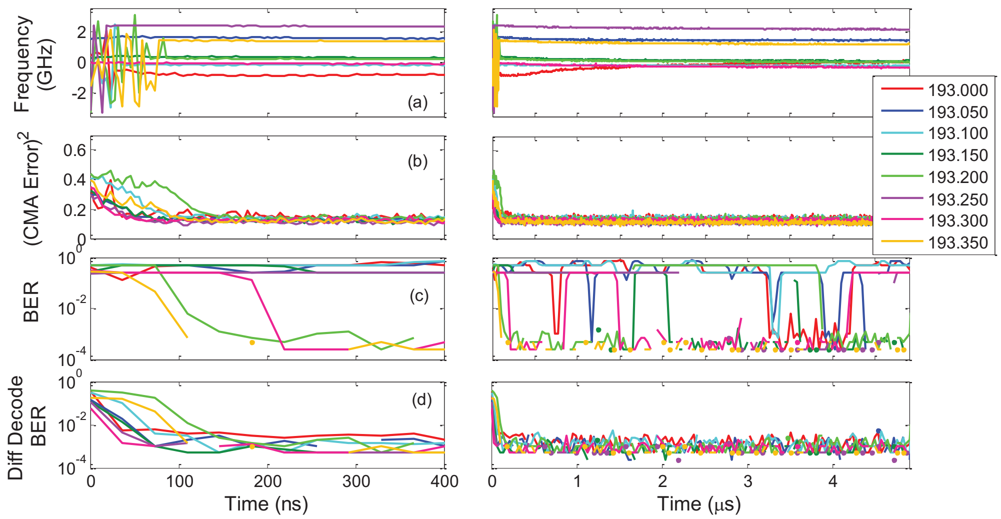

Fig. 2 Burst mode receiver performance for 8 consecutive bursts overlaid, in terms of (a) the estimated frequency offset, (b) the CMA error, (c) standard BER and (d) the differentially decoded BER. The left and right panels show the initial 400 ns and the entire 5 μs burst, respectively.

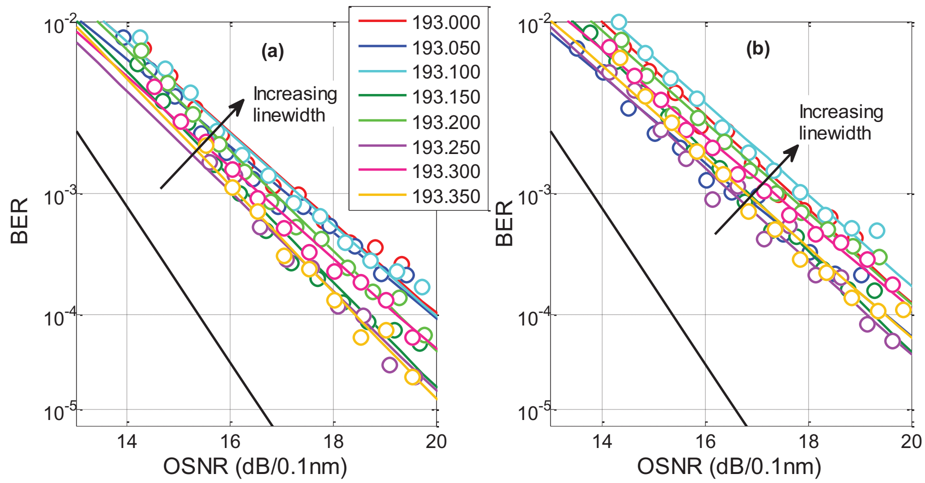

Fig. 3 Differentially decoded BER performance as a function of received ONSR for the eight 50 GHz spaced channels under burst switched operation. The BER is shown for both back-to-back (a) and after 240 km of SMF (b). Also shown is the theoretical maximum (solid black line)

4. Conclusions

We have implemented a 112 Gb/s coherent burst mode receiver using a parallel processing DSP architecture that is suitable for implementation on a ASIC with a 218.75 MHz clock speed. We find that differential decoding is essential for operation with the larger linewidths that are encountered when using fast tunable lasers. The receiver differentially decoded BER was demonstrated to converge to below the FEC limit within 150 ns both under back-to-back and after transmission over a 240 km uncompensated link.

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