Fast Wavelength Switching DP-OFDM Transceiver in a 5-Node 800km Coherent OBS Network

Robert Maher, Hou-Man Chin, Manoj P. Thakur, Domaniç Lavery, Polina Bayvel, Seb J. Savory and Benn C. Thomsen

Optical Networks Group, University College London, Torrington Place, London WC1E 7J3, UK

r.maher@ucl.ac.uk

Abstract: Fast wavelength switching OFDM transceiver enables the coherent reception of 2-burst channels within a 1dB penalty after 800km transmission. Burst detection and variable path-history compensation are performed using inherent OFDM synchronization symbols and cyclic prefix.

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1. Introduction

The combination of fast wavelength switching monolithically integrated tunable lasers, higher order modulation formats and coherent reception provides the platform for a dynamically reconfigurable inter-data center optical network, where rapid bandwidth provisioning can be performed using sub-wavelength optical switching in nanosecond time frames. By performing burst switching in the optical domain, the physical network can be virtualized through a distributed optical layer 2 switch, while also enabling sub-wavelength optical bypass to ensure that through traffic does not consume network-interface bandwidth or switching resources. This results in greater utilization of the available system bandwidth and transceiver line cards, while simultaneously reducing power consumption and cost [1].

Recent research in coherent optical burst switching has focussed on the real-time implementation of a digital burst mode receiver and the development of optimized training symbols to reduce equalizer convergence times, thus enabling rapid burst acquisition [2–5]. The authors have previously demonstrated the performance of fast wavelength switching burst mode DP-QPSK and DP-OFDM transceivers, that utilize monolithically integrated tunable lasers at both the transmitter and as the local oscillator (LO) within the digital coherent receiver [6–8]. The OFDM modulation format is of particular interest to optical burst switching as the training symbols and cyclic prefix (CP) that are inherent to the OFDM modulation format can be exploited for burst detection and to negate the requirement for fast channel dispersion estimation [8, 9].

In this work, we demonstrate for the first time, to the best of our knowledge, a fast wavelength switching DP-OFDM digital coherent transceiver in a 5-node 800km optical burst switched network (OBS). It is shown that the OFDM frame synchronization and CP can be exploited to receive optical bursts that exhibit a variable path history. An OSNR penalty of $<$1dB (relative to B2B) was experienced for all received bursts over the 800km burst switched network.

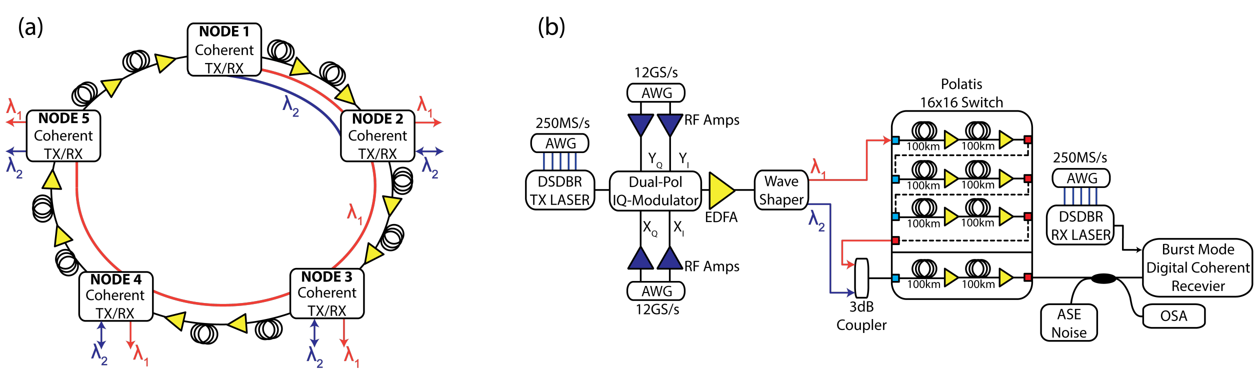

Fig. 1. (a) 5-node burst switched ring architecture and (b) experimental setup.

2. 5-node Optical Burst Switched Network

The 5-node optical burst switched network employed in this work is illustrated in Fig. 1(a). Each node consists of a fast wavelength switching transceiver and are separated by two 100km spans of standard single mode fibre (SMF). Two burst channels are employed to evaluate the performance of the system. Burst channel one (CH1) originates at node 1 and the performance of this channel is analyzed at each transceiver node, with a maximum transmission distance of 800km. Burst channel two (CH2) is only transmitted over the last 200km in each scenario. Therefore at node 2, both burst CH1 and CH2 have traversed 200km, however for node 3 CH1 will have propagated 400km, while burst CH2 will still have only propagated 200km (as it is added at node 2) and so on. By increasing the transmission distance of burst CH1 and maintaining a constant transmission distance for burst CH2, the differential transmission distance (path history) between the bursts can be varied.

Fig. 1(b) illustrates the experimental setup employed to realize the 800km burst switched ring. A commercially available DS-DBR tunable laser switched between two 50GHz spaced channels on the ITU grid (λ_1: 1553.22nm and λ_2: 1552.83nm), with a burst length equal to the OFDM frame period ($\sim 7\mu$s). Two 12GS/s arbitrary waveform generators (AWG) provided the in-phase and quadrature components for each polarization, which were subsequently applied to an integrated dual polarization IQ modulator. The net bit rate per channel after the OFDM and forward error correction (FEC) overhead had been removed was 18Gb/s. A DC pilot tone was added on the X-polarization by slightly detuning the bias of the IQ modulator to aid the compensation of the transmitter and receiver laser phase noise, as described in [8]. A programmable filter was used to split the two burst channels into separate transmission paths.

The transmission line consisted of eight 100km spans of SMF (arranged in 200km links), which were each followed by a gain-flattened EDFA. A Polatis 16x16 low loss optical switch was used to reconfigure the transmission spans and to position the digital coherent burst mode receiver at each of the five nodes. After the transmission distance was set for CH1, both channels were combined using a 3dB coupler before traversing the final 200km. The coherent burst mode receiver utilized a second DS-DBR laser as the LO and the frequency was tuned to coincide with the transmitted burst channels. The transmitted channels were coherently detected and digitally processed offline. An amplified spontaneous emission (ASE) noise source was employed to vary the received OSNR for bit error rate (BER) analysis.

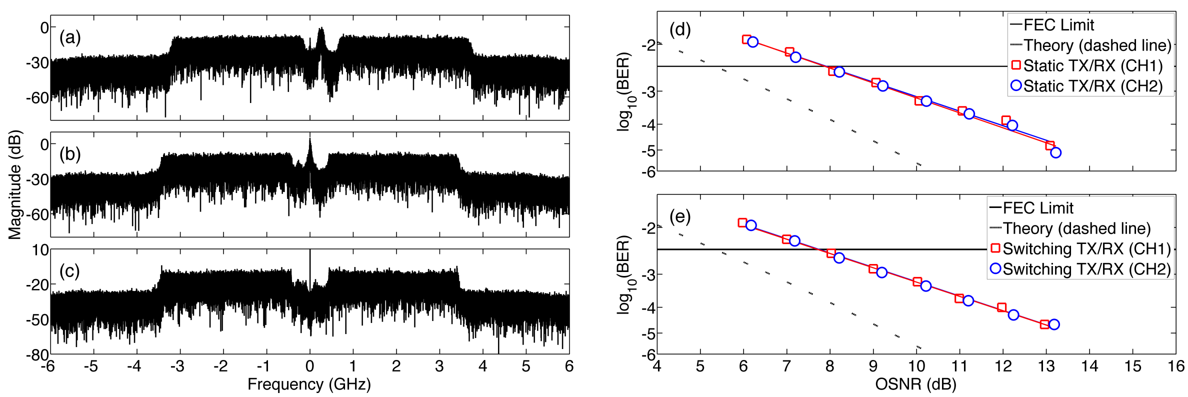

Fig. 2. Received OFDM spectrum, (a) at the receiver, (b) after block based FO compensation and (c) after pilot tone based carrier phase compensation. BER performance for, (d) two static wavelength channels and (e) two dynamic burst channels.

3. Results and Discussion

The back-to-back BER performance of the DP-OFDM transceiver was initially characterized when both transmitter and receiver LO DS-DBR lasers were operated in static mode (not switching). The received OFDM spectrum is shown in Fig. 2(a). The varying intermediate frequency of the beat note between the transmitter and receiver tunable lasers was initially compensated using a block based frequency offset (FO) estimator [6]. This down-converted the OFDM signal to baseband, as seen in Fig. 2(b) and enabled the DC pilot tone to be low pass filtered. The carrier phase was subsequently estimated using a mean feed-forward phase estimator and applied to the received signal to compensate for the combined phase noise of the transmitter and receiver lasers, as seen in Fig. 2(c). It is important to note that the DC pilot tone based phase noise compensation scheme is a pre-requisite when using commercially available DBR based fast tunable lasers and the OFDM modulation format. The BER performance of the OFDM transceiver, when operating in static mode is illustrated in Fig. 2(d). An implementation penalty of 2.6dB was observed with respect to theory at a FEC limit of $3.8\text{x}10^{-3}$ for both burst CH1 (λ_1: 1553.22nm) and CH2 (λ_1: 1552.83nm). No additional OSNR penalty was incurred when both the transmitter and LO DS-DBR lasers were dynamically switched between the two burst channels, as demonstrated in Fig. 2(e).

In order to characterize the transmission performance of the OFDM transceiver, the transmitter DS-DBR laser was switched between the two burst channels, while the LO DS-DBR laser resided at each wavelength channel for two burst periods before switching. This was required for asynchronous detection, as the burst channels experience different propagation delays through the network, therefore the LO must wait at a desired wavelength channel until the burst has been received. The CP length was set to 30 symbols, which was sufficient for a transmission distance greater than 1000km. Burst detection was achieved by searching for the OFDM frame synchronization symbols at the start of each burst, as seen in Fig. 3(a). Once each optical burst was detected the remaining DSP blocks were applied, as described in [8]. Fig. 3(b) and (c) illustrate the burst amplitude and block based frequency offset estimation across each burst channel. The average FO for burst CH2 was approximately 100MHz, while it was 300MHz for CH1.

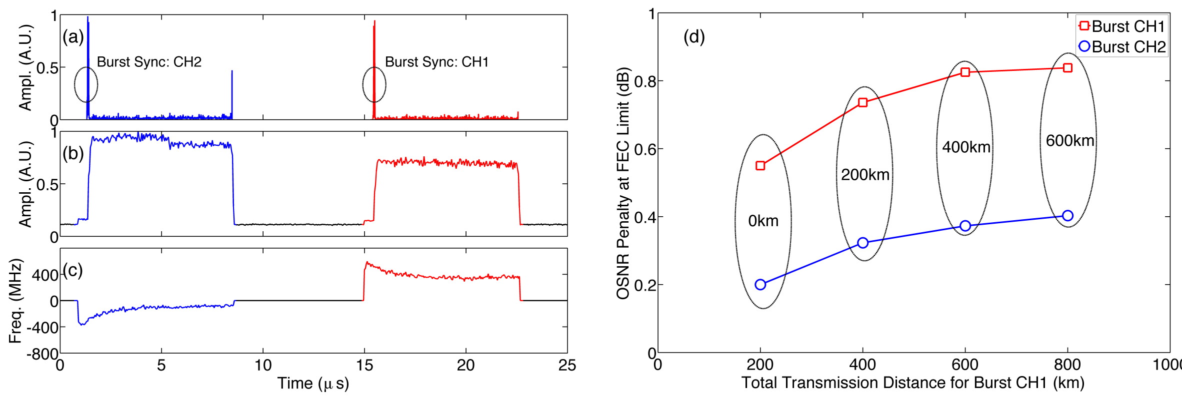

Fig. 3. (a) Burst detection, (b) received burst amplitude, (c) block based FO estimation and (d) OSNR penalty as a function of the total and differential transmission distance for both burst channels.

The OSNR penalty, relative to the B2B case (Fig. 2(e)), for the 5-node 800km optical burst switched network is shown in Fig. 3(d). After 200km transmission from node 1 to node 2, a slightly larger OSNR penalty of 0.55dB was experienced for CH1 relative to 0.2dB for burst CH2. The slope of the OSNR penalty as a function of transmission distance is also similar for both burst channels. A constant penalty is expected for CH2 as it propagates over a constant transmission distance (200km), however accumulated ASE noise from burst CH1 is added to CH2 in the 3dB coupler, which results in an increase in OSNR penalty with distance. However, the difference in OSNR penalty between burst channels remains almost constant as the differential transmission distance increases from 0 to 600km. This demonstrates that the CP inherent to the OFDM modulation format completely compensates the accumulated chromatic dispersion of each optical burst channel and demonstrates that fast dispersion estimation is not required for an OFDM based OBS network. The maximum excess penalty for burst CH1 (relative to the B2B switching case) remains below 1dB after transmission over 800km of SMF. This penalty is caused by a trade-off between low launch power to minimize fiber non-linearity and OSNR degradation due to the 100km span loss. The OSNR penalty could potentially be improved by either reducing the span length or by utilizing ultra low loss fibre.

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