A 32×10 Gb/s OLT Using a Single Ultra-wide Bandwidth Dual Local Oscillator Coherent Receiver

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***Abstract*—Detection of a 32×10 Gb/s channel UDWDM-PON in a single, wide bandwidth coherent receiver is enabled using two, frequency-separated, local oscillator lasers. The preservation of receiver linearity is demonstrated through digital dispersion compensation and channel isolation after 80 km transmission.**

I. INTRODUCTION

Over the previous decade, many optical communications links have been upgraded to use coherent receivers and advanced modulation formats. The motivation for core networks is the advantage of coherent systems in terms of spectral efficiency and transmission reach. The advantages of coherent detection for passive optical networks (PON) are similarly clear: high sensitivity, frequency selectivity, and linear detection[1]. However, the complexity of phase- and polarization-diverse coherent receivers has excluded them from consideration in cost-sensitive access networks. And yet, there are examples where coherent receiver designs have been tailored to access networks, using application-specific digital signal processing (DSP)[2], or by simplifying the receiver structure [3], [4] to be comparable with the mainstay; direct detection.

In a recent ultradense wavelength division multiplexed (UDWDM)-PON demonstration[1], a coherent receiver-based optical line terminal (OLT) was used to detect 5×10 Gb/s upstream channels simultaneously. A cost advantage can be gained by using a single device to receive several channels, however aggregating just five channels may not justify the complexity of coherent detection. Herein, we introduce a fundamentally new dual-local oscillator laser (LO) technique to enhance the usable receiver bandwidth; aggregating 32×10 Gb/s upstream channels in a single receiver.

In this manuscript, we claim the first single-receiver 320 Gb/s upstream transmission in a UDWDM-PON configuration, the proposal and demonstration of a dual-LO coherent optical receiver, and the record widest operational optical bandwidth single coherent receiver (although not the widest optoelectronic bandwidth) used for optical fiber communications (208 GHz). This proof-of-principle demonstration raises a potentially disruptive cost-performance trade-off, as we show that the number of receivers required per OLT can be substantially reduced by using this technique.

II. BANDWIDTH-EXTENDED DUAL LO RECEIVER

The frequency selectivity of a coherent receiver – the ability to mix an arbitrary frequency range to baseband – is due to the coherent mixing of the input signal with the local frequency reference; the LO. By mixing two LOs into a single receiver at different frequencies, different frequency ranges are mixed to baseband, meaning a wider range of channels can be simultaneously received. Linear crosstalk between channels in each frequency range is avoided by exploiting the spectral gaps inherent to the PON configuration, as shown in Fig. 1.

This technique is naturally applicable to bidirectional UDWDM-PONs, where channels are transmitted on a dense frequency grid but with a spectral gap to facilitate heterodyne detection of the downstream signal, and mitigate optical network unit (ONU)-side backscatter crosstalk. Upstream signals are necessarily frequency locked to the downstream signal, and transmitted upstream in the spectral gaps, thus maintaining a regular frequency grid, but frequency shifted versus the downstream signal. The received signal configuration at the OLT is shown in Fig. 1 [left]. The dual-LO configuration produces a bandwidth-efficient digital spectrum (Fig. 1 [right]). For zero inter-channel crosstalk, channels on a $2f$ [Hz] frequency grid must be detected with LOs spaced at $(n + 0.5)f$, $n \in \mathbb{N}_0$. Although linear detection is preserved when using the dual-LO technique, the use of additional LO lasers increases the LO-noise beating term giving a signal-to-noise ratio degradation of $10 \log 10(N_{\mathrm{LO}})$ [dB]. This is an acceptable performance degradation, considering the significantly decreased number of receivers required at the OLT.

III. EXPERIMENTAL CONFIGURATION

We select the system parameters similarly to [1]; without polarization multiplexing at the ONU. For this UDWDM-PON experiment, 32 upstream channels were generated usng four external cavity lasers (λ=1549.6, 1550.0, 1550.4, 1550.8 nm).

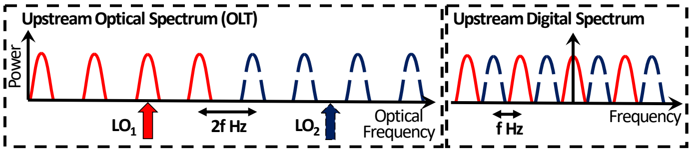

Fig. 1. Principle of operation: the two local oscillator lasers are centered on frequencies as shown in the optical spectrum schematic (left). After coherent detection, the high frequency channels (blue dashed) are mixed into the spectral gaps (right).

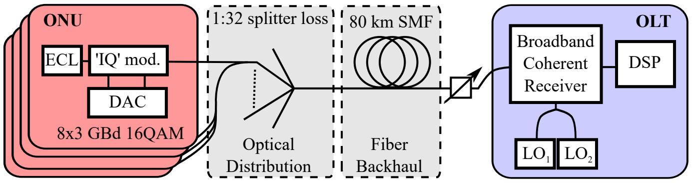

Fig. 2. Experimental configuration. The four transmitters combined emulate the upstream signal from 32 ONUs.

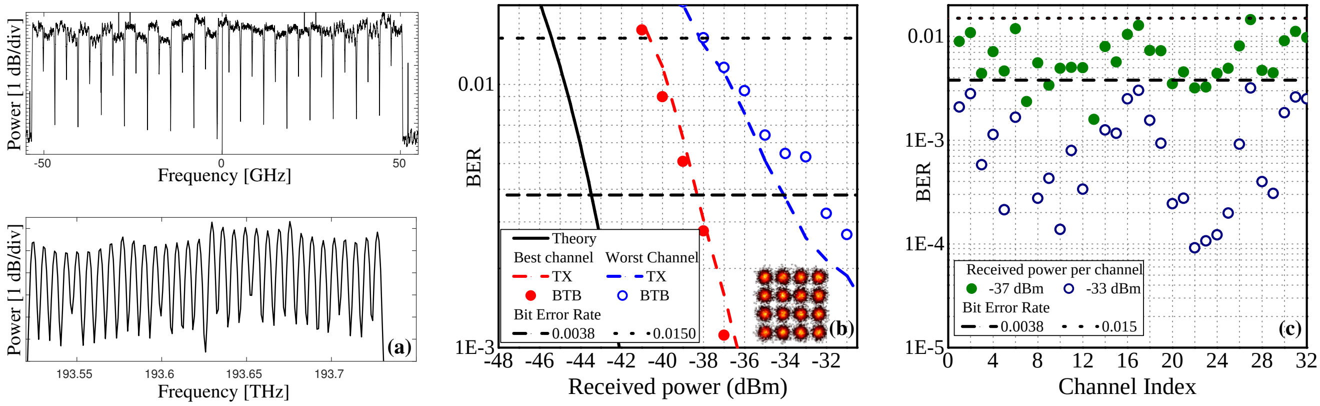

Fig. 3. (a) Digital (top) and optical 0.02 nm resolution (bottom) spectra at the OLT, (b) back-to-back and transmission performance for best- and worst-performing channels. The theoretical curve includes both LO shot noise contributions. (c) The sensitivity at the FEC thresholds after transmission.

These lasers have a 100 kHz linewidth and -150 dBc/Hz relative intensity noise, comparable to modern, C-band tunable, volume-production semiconductor lasers [5]. The sources were coupled into ‘IQ’ modulators (15 GHz electronic bandwidth) and driven with a 90 GSa/s digital-to-analog converter (DAC) to generate 8×3 GBd root raised cosine pulse shaped (roll-off, 0.1) 16-*ary* quadrature amplitude modulation (16QAM) subcarriers per wavelength (Fig. 2). In total, 32×10 Gb/s subcarriers (assuming 20% coding overhead) were generated with a subcarrier spacing of 6.5 GHz. This signal (2.5 dBm/channel) was attenuated to emulate a 1:32-way splitter loss (15 dB), followed by transmission over 80 km standard single mode optical fibre (15.6 dB span loss). The signal was received using a phase- and polarization-diverse coherent receiver and digital sampling oscilloscope (160 GSa/s) with a combined optical bandwidth of 120 GHz. Note that the photodetectors did *not* include transimpedence amplifiers (TIA), so this limitation was overcome by preamplifying the signal using an EDFA (noise figure 5.5 dB). The receiver used two LOs separated by 103 GHz, and centered about 1549.8 and 1550.6 nm, with -8 dBm power per LO onto each balanced photodiode. Each channel was digitally frequency shifted to DC and resampled to 2 Sa/symbol. The channels were then processed using a 31-tap adaptive, multi-modulus, equalisation algorithm to simultaneously compensate chromatic dispersion, apply a matched filter, and recover the state of polarization, followed by a fourth power frequency offset estimator, 16-tap decision-directed phase recovery and bit error rate (BER) estimation.

IV. RESULTS AND DISCUSSION

Fig. 3(a, bottom) shows the optical spectrum analyser trace for the received optical signal, while Fig. 3(a, top) shows the same signal after reception using a dual-LO coherent receiver. Note that the effective spectral occupation is doubled after the coherent receiver. The performance of the best- and worst-performing channels is shown in Fig. 3(b). For this investigation, we consider two BER thresholds for forward error correction (FEC); 3.8×10^{-3} and 1.5×10^{-2}, a conventional 7% overhead and an advanced 20% overhead hard decision code, respectively, as in [1]. We observe no significant performance difference between back-to-back and transmission and conclude that, as anticipated, the linear detection characteristic of the receiver is preserved.

Although crosstalk due to OLT-side reflections can be mitigated in several ways (e.g., half-duplex transmission for the fiber backhaul, or an optical circulator placed before the OLT) we suggest that the use of an optical interleaver prior to the coherent receiver would remove backreflections, whilst reducing the inherent 3 dB penalty of this technique. This would be in lieu of the arrayed waveguide grating which would otherwise be required for separate receivers, and thus does not increase complexity. As shown in Fig. 3(c), after 80 km transmission (a distance commensurate with a long-reach PON) the performance is unaffected by the non-deterministic received state of polarization or the accumulated chromatic dispersion. The performance variation between channels is mainly due to the limited bandwidth of the ‘IQ’ modulators used for subcarrier generation. Nevertheless, at either the 7% or 20% overhead FEC threshold, it is possible to transmit 80 km with a 1:32-way split. We observe a 4.9 dB (8.9 dB) excess power budget at the 7% (20%) FEC thresholds, respectively. Overall, the results in Fig. 3 show that the proposed dual-LO technique can receive 32 channels with excellent sensitivity. For a comparable configuration to the recent record 1.92 Tb/s PON [1], just 6 coherent receivers would be required at the OLT to receive all 192×1 Gb/s channels.

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