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Mixed DD and Coherent Receivers for VHSP using Digital CD Pre-Compensated PAM-2

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Abstract *In the ongoing research towards next-generation Very High Speed PON, we propose and experimentally investigate the combination of Digital Chromatic Dispersion Pre-Compensation (DCPC) PAM-2 transmission with coexisting mixed receivers: DD for PON up to 20km and coherent detection for extended reach up to 40+km.* ©2026 The Authors

Introduction

Several physical layer options are currently being analyzed for Very High Speed PON (VHSP) to increase the capacity of passive optical networks (PONs) towards 200G net data rate [1]. Among the main alternatives, Digital Chromatic Dispersion Pre-Compensation (DCPC) is a possible solution for downstream (DS) to reduce chromatic dispersion (CD) effect while still employing direct-detection (DD) ONU receivers as studied in [2–5]. Using variants of this basic idea, it was demonstrated that 100G per λ transmission and DD detection would be possible over 20-km in the O-band [6] using a DCPC optical duobinary, or in C-band using PAM-4 [7]. However, the DCPC technique can compensate for a specific interval of accumulated CD values and may thus require transmitting different signals depending on the CD experienced by the ONUs inside a given Optical Distribution Network (ODN).

In this paper, we analyze the hybrid extension shown in Fig. 1 of the DCPC DS concept, to be compliant with two types of receivers:

- "standard" DD (indicated as DD-ONU in this work) for ONUs localized within the standard ITU-T distance range (up to 20 km) and hence accumulated CD.
- coherent receivers (COH-ONU in this work) for individual scattered ONUs and longer distance (i.e. higher CD), typically for extended reach VHSP beyond 20 km.

As we will show in the following experimental part of the paper, coherent detection DSP can easily compensate CD, as known in metro and transport networks. Moreover, thanks to its higher received optical power (ROP) sensitivity, it enables higher achievable ODN loss compared to the DD-ONUs. We will show that the two detection alternatives can coexist in the same DS PON. Besides proposing the hybrid DD and COH architecture in DS DCPC, the novelty of our paper is in the specific DSP chain required in the COH case for receiving DCPC PAM-2 and in assessing the ultimate performance of the COH case.

Architecture and Experimental Setup

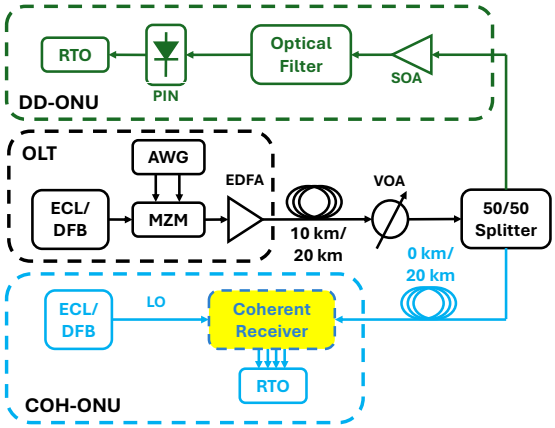


Fig. 1: Experimental setup. A 50-Gbaud PAM-2 signal is generated at the OLT with DCPC of 340 ps/nm. After transmission, the signal is split in two arms. At one arm, the DD-ONU receives the signal with direct detection. On the other arm, a COH-ONU receives a signal with a better sensitivity, optionally after transmission over additional 20-km SMF.

A high-level block diagram of the proposed architecture is shown in Fig. 1. At the transmitter (TX), a DCPC 50-Gbaud PAM-2 signal is generated using an external I/Q Mach-Zehnder Modulator (MZM) driven by two DCPC electrical signals generated by a 92 GSa/s Arbitrary Waveform Generator (AWG). The CW laser is either an External Cavity Laser (ECL) with a linewidth < 100-kHz or a Distributed Feedback Laser (DFB) with a ~ 2-MHz linewidth. Both lasers emit in the C-band (≈ 1550 nm). The DCPC is set to pre-compensate the dispersion induced by 20-km of SMF in C-band ($D \cdot L \simeq 340$ ps/nm). A booster EDFA is used to set the transmit optical power to $+11.3$ dBm.
Then, the signal is transmitted over 20-km SMF, followed by a variable optical attenuator (VOA) that

allows emulation of high ODN loss. To assess the robustness of a single DCPC setting, we also evaluate a "mismatched" case, replacing the 20-km SMF with a 10-km one. Afterwards, the optical signal is split in two branches using a 3-dB coupler. One branch goes to the DD receiver (DD-ONU), which consists of a Semiconductor Optical Amplifier (SOA), followed by an optical band-pass filter to remove ASE noise outside of the signal's bandwidth and a PIN photodiode. A second branch goes to another 20-km of SMF, followed by a COH-ONU, built with a commercial dual-polarization integrated coherent receiver (ICR, no SOA was used in the COH branch). The Local Oscillator (LO) is again either a DFB or an ECL, with similar characteristics as the transmit laser. The detected electrical signals are then digitized using a Real-Time Oscilloscope (RTO) and post-processed by proper off-line DSP algorithms. For the DD receiver, the DSP chain consists of a 100-tap Least-Mean-Squares (LMS) Feed-Forward Equalizer followed by a 5-tap Decision-Feedback Equalizer.

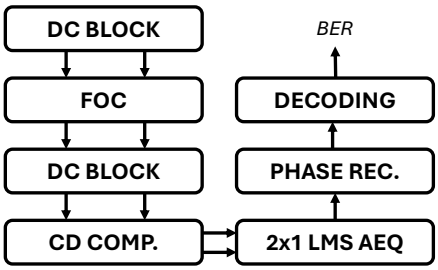


Fig. 2: DSP chain for the coherent receiver.

For the COH receiver, a block diagram of the DSP chain (implemented off-line in our experiments) is shown in Fig. 2. In general, it resembles a standard DSP chain for COH [8], with some modifications required to make it compliant with a DCPC PAM-2 transmitted signal that, contrary to usual DP-QAM transmission, has a strong optical DC component and it is fully polarized. A first DSP-based DC block filter removes the residual carrier induced by the LO that is not filtered by the ICR's internal hardware AC-coupled circuits. Then, after blind periodogram-based Frequency Offset Compensation (FOC), a second DC block removes the carrier of the DCPC PAM-2 signal. A complex-valued 2×1 MIMO LMS adaptive equalizer is used to reduce inter-symbol interference and to make the RX fully polarization-insensitive. This equalizer employed 50 half-symbol-spaced taps. After equalization, a fully blind 2^{nd}-power carrier phase recovery removes the residual carrier phase, followed by hard decision and error counting.

Experimental results

The first set of results is shown Fig. 3, where an ECL was used both at TX and at the COH RX. The figure shows the measured BER vs. ODN loss for

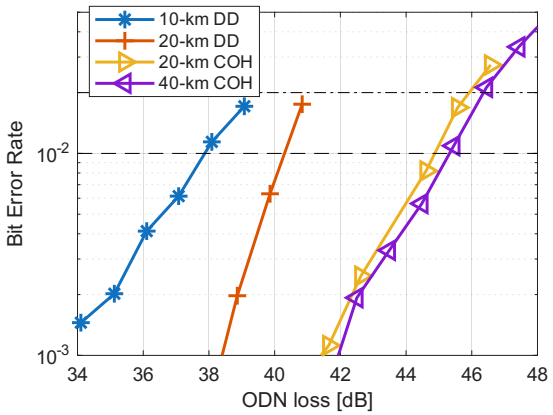


Fig. 3: Experimental results, obtained employing two ECLs at the transmitter and coherent receiver, with 20-km DCPC applied at transmitter.

two receivers (DD and COH) and three distances. The blue asterisks and red crosses are obtained with a DD receiver at 10 and 20 km fiber lengths. Since the DC pre-compensation is optimized for 20-km, the 10-km case experiences residual CD, resulting in a ~ 2-dB CD-induced penalty at 10^{-2} BER. At 20 km, the system achieves this BER with an ODN loss of approximately 40.3-dB, and a BER of $2 \cdot 10^{-2}$ at 41-dB. The COH receiver placed at the extended reach distance of 40-km (purple triangles) achieves a better sensitivity of $\simeq 5$-dB at BER=10^{-2} and $\simeq 5.3$-dB at BER=$2{\cdot}10^{-2}$. The same figure also shows COH receiver performance at 20-km (yellow triangles), and the resulting sensitivity curve is almost identical to the 40-km results, showing that (as expected) CD does not represent a limiting factor for the COH receiver in the considered scenario. Moreover, the better performance in achievable ODN loss for (not optically amplified) COH receiver is simply due its intrinsically higher sensitivity (as shown in [9]).

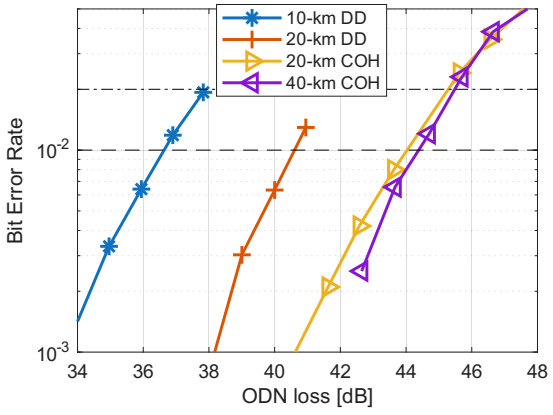


Fig. 4: Experimental results, obtained employing a DFB at both transmitter and coherent receiver, with 20-km DCPC applied at transmitter.

In a second set of experiments, we used DFB lasers at both TX and COH RX, a cost-effective alternative in the PON context compared to ECLs. Results are shown in Fig. 4. The COH RX has a ~ 1-dB penalty compared to the two ECLs case. This is due to the much stronger phase noise,

and also a stronger residual DC carrier, which required a bandwidth increase of the two DC-block filters. Nevertheless, the COH RX still achieves better sensitivity of approximately 4-dB at a BER of 10^{-2} with respect to the DD receiver at 20-km, and it confirms its immunity to CD. These results were also extended to a "mixed laser" scenario, where an ECL is used at the OLT, and a DFB at the COH-ONU. Results (not shown for space limitation) were, as expected, between those of Fig. 3 (two ECLs) and Fig. 4 (two DFBs).

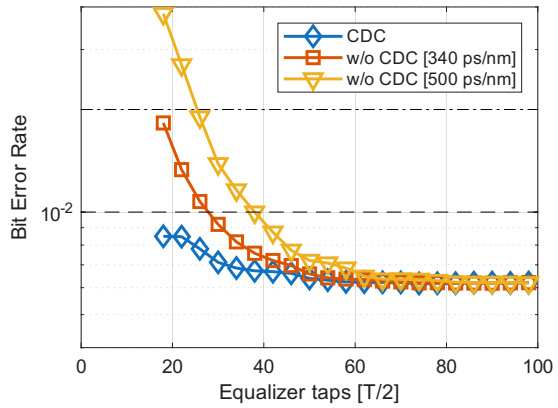


Fig. 5: BER as a function of the number of taps of the 2×1 adaptive equalizer at 43.7-dB ODN loss. The system employed a DFB laser at both transmitter and COH receiver. Blue line: full digital compensation of CD at receiver with a dedicated CDC algorithm. Red and yellow line: compensation of different values of CD at receiver using only the adaptive equalizer.

For the COH RX, we then focused our attention on some specific aspects of the RX DSP. Standard COH RX for long-haul networks employ algorithms to estimate CD, which is then used in specific CD compensation (CDC) DSP algorithms [10]. However, such techniques may not work with DCPC PAM-2 transmission and, more importantly, a fully-static CDC at the receiver would reduce the complexity and power consumption of the DSP. Therefore, in Fig. 5 we compare the BER of a signal detected with the COH receiver at 43.7-dB ODN loss, when employing a DFB at both TX and RX. The blue line shows the BER with a CDC block set at 340 ps/nm, which corresponds exactly to the accumulated dispersion after 20-km SMF. The red line, instead, shows the BER of the same system, but without any dedicated CDC filter at the coherent receiver. This means that the residual dispersion of 340 ps/nm is only compensated by the aforementioned 2x1 MIMO adaptive equalizer. With few taps, the difference between the two curves is significant. However, when reaching the optimal number of taps ($\simeq$50), which is the number used for previous results, the two curves superimpose. Therefore, we can conclude that, in this scenario, dedicated CD-estimation and CD-compensation blocks at the COH RX DSP are not required.

Scaling results to 120-Gbaud in O-band

Experiments were conducted at 50 Gbaud PAM-2, limited by the available laboratory hardware, while operating in the C-band to induce a high accumulated CD of 340 ps/nm. Anyway, the current VHSP target is (at least) a DS net data rate of 100 Gb/s per λ. Assuming a 20% overhead FEC, this can be achieved using 120 Gbaud PAM-2 transmission in the O-band. It this section, we thus investigate the resulting scaling factors. In O-band, the fiber attenuation is slightly higher ($\sim$0.4 dB/km) than in C-band, whereas the worst-case CD is significantly lower (we will assume here 6 ps/(nm·km) for upper O-band). Assuming a 40-km extended reach distance, the resulting fiber loss amounts to 16 dB. By including an additional 23 dB splitter loss, corresponding to a $1{:}128$ splitting ratio, the baseline ODN loss is in the 39 dB range. As shown in Fig. 4, a target BER of 2×10^{-2} is achieved at approximately 45 dB ODN loss. This margin is sufficient to accommodate the baseline 39 dB ODN loss plus extra losses, even when accounting for the expected additional 3.8 dB penalty (i.e. 120/50 in dB) associated with the increased symbol rate. Regarding CD, the required number of taps for COH compensation scales approximately as $|D_\lambda| \cdot \lambda^2 \cdot R_s^2$ [8], where λ is the central wavelength, D_λ is the fiber CD parameter and R_s the symbol rate. Consequently, the number of taps is expected to increase by approximately:

$$\left(\frac{6\ \frac{\text{ps}}{\text{nm}\cdot\text{km}}}{17\ \frac{\text{ps}}{\text{nm}\cdot\text{km}}}\right)\left(\frac{1310\ \text{nm}}{1550\ \text{nm}}\right)^2\left(\frac{120\ \text{Gbaud}}{50\ \text{Gbaud}}\right)^2 \approx 1.5$$

To emulate this condition, the yellow line in Fig. 5 shows results without any CDC block at the receiver, where the residual dispersion was digitally increased to 500 ps/nm. This represents an increase by approximately 50%, which results in performance similar to 120-Gbaud transmission in the O-band. As can be seen from the plot, the equalizer requires more taps to achieve the optimal performance but the resulting number ($\simeq 65$ taps in our case to have negligible penalty) is still within the acceptable range for COH RX.

Conclusions

We proposed and experimentally demonstrated a DS solution based on DCPC-PAM-2 OLT TX and two types of ONU RXs: a standard DD receiver for regular distance up to 20km, and a COH receiver for extended-reach (which we tested up to 40-km, but can likely be enlarged even further if needed). Results showed that, even when using DFB lasers at both TX and RX, COH performance is largely immune to CD and provides better receiver sensitivity (compared to DD) by $\simeq 5$-dB at BER=$2 \cdot 10^{-2}$, allowing proportionally higher achievable ODN loss, as required by the additional loss introduced by an extended reach target.

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