Cost Effective 100G Coherent PON Enabled by Remote Tone Delivery and Simplified Carrier Recovery for Burst Processing

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Abstract *We present a remote optical tone delivery and simplified DSP algorithms for low-cost implementations of 100G TFDM coherent PON. A 50 km upstream burst transmission with 32 split experimental demonstration has been successfully achieved with similar performance compared to a regular ECL-based system. ©2023 The Author(s)*

Introduction

Optical access networks are progressing towards improved capabilities to handle heavy data stream with greater reach and penetration [1, 2]. Passive optical network (PON) dominates the short-reach access market due to its efficient resource sharing, but future 100G and higher capacity PON faces challenges with current intensity-modulation direct-detection (IM-DD) technology [1-3]. Coherent technology is a future-proof solution with high capacity and improved receiver sensitivity. Time and frequency division multiplexing (TFDM) coherent PON is a promising contender for next-gen access networks, offering great flexibility leveraging time and frequency domain bandwidth sharing [4-10]. TFDM offers advantages in terms of flexibility and simplicity over traditional PON technologies (i.e., time division multiplexing (TDM) and wavelength division multiplexing (WDM)), without requiring multiple wavelengths and colored optics.

High component costs associated with existing coherent optics mainly come from high-quality optical sources like external cavity lasers (ECLs) [11]. For access applications, optical injection locking (OIL) using Fabry-Perot laser diodes (FP-LDs) presents a feasible solution to enable introduction of cost-effective coherent optics into PON [12-14]. In a conventional coherent PON, an optical master tone for OIL overlaps with downstream coherent signals, resulting in signal transmission errors. TFDM technology allows an optical master tone to be coupled between two adjacent subcarriers, enabling low-cost optical network unit (ONU) devices through OIL in a single fibre configuration.

In this work, we propose a novel architecture for TFDM coherent PON, replacing expensive ECLs with more affordable FP-LDs through OIL. Experimental demonstrations show no significant degradation in performance compared to a regular ECL-based system. Frequency locking between ONU and optical line terminal (OLT) light sources benefits the proposed architecture by mitigating random frequency drifts and simplifying receiver digital signal processing (DSP) through removing of carrier frequency offset (CFO) compensation processes. This work extends our recent publication [9], achieving successful demonstration of upstream transmission in burst TFDM signals and further simplifying receiver DSP.

Operational Principles

Fig. 1(a) shows the proposed TFDM PON structure with high flexibility for bandwidth allocation. In the downstream (DS) direction, two TFDM subcarriers each running at 50 Gb/s (12.5 GBd dual polarization (DP)-quadrature phase shift keying (QPSK) signal) are generated over frequency f_1 at the OLT, coupled with two optical tones at f_1 and f_2. The DS TFDM signals are broadcasted in continuous mode. At the ONU,

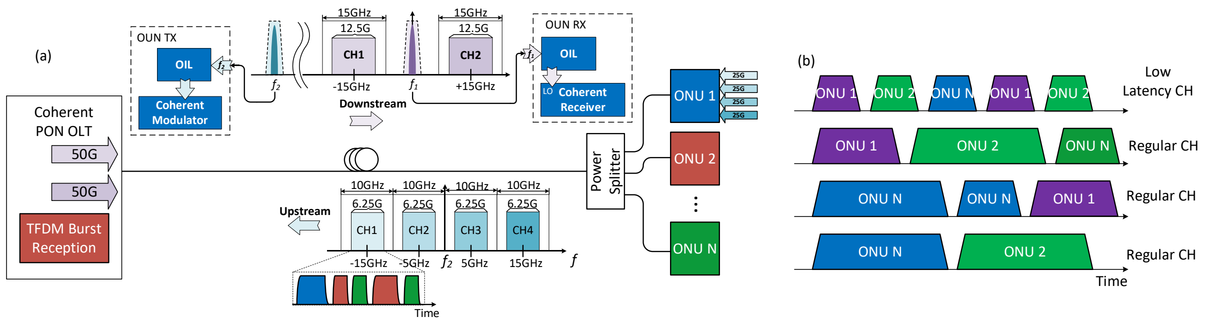

Fig. 1: (a) Coherent TFDM PON architecture featuring remote optical tone delivery and upstream burst; (b) TFDM upstream burst distribution in subcarriers.

the f_1 optical tone is used as master light source for OIL to generate local oscillator (LO) and detect DS signals. Where the f_2 optical tone serves as the master light source for OIL to generate an optical carrier for upstream (US) signal transmission. The f_1 and f_2 are spaced 100 GHz apart to align with the ITU DWDM frequency grid. In the US direction, four TFDM subcarriers each at 25 Gb/s (6.25 GBd DP-QPSK signal) are transmitted in TDM burst mode. OIL process amplifies both tones, removing the need for extra optical amplifiers. Fig. 1(b) illustrates TFDM operation with burst transmission, allowing for two-dimensional bandwidth resource allocation and dynamic configuration of consecutive bursts in one of the TFDM subcarriers for minimal latency.

Fig. 2 illustrates the DSP procedures for the proposed coherent TFDM transmitter, receiver, and burst preamble design. The transmitter DSP as shown in Fig. 2(a) involves burst frame generation which required only for US burst transmission and not included in DS broadcasting, and subcarrier processing, with the burst frames or data frames assigned to each subcarrier after Nyquist pulse shaping and digital up-conversion. The receiver DSP as shown in Fig. 2(b) includes down-conversion, fast Fourier transform (FFT), filtering, and inverse fast Fourier transform (IFFT), followed by burst signal

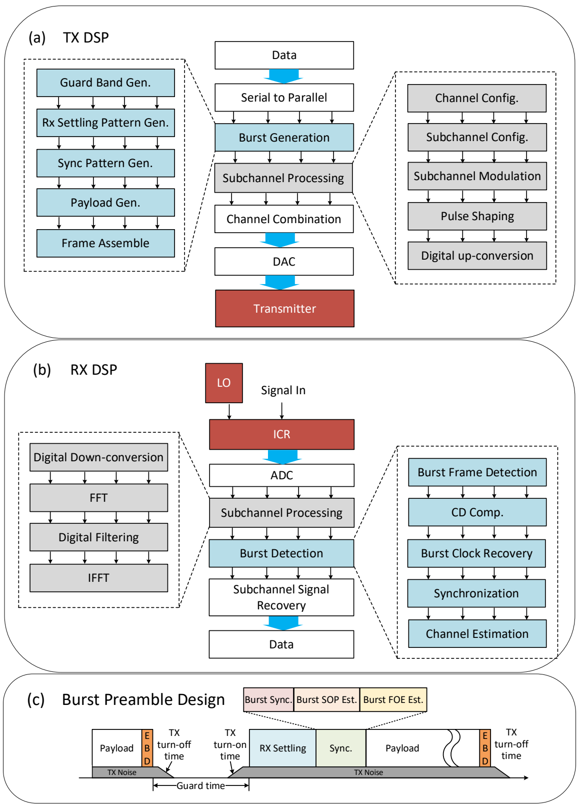

Fig. 2: (a) TFDM Tx DSP procedures; (b) TFDM Rx DSP procedures; (c) Preamble design in TFDM burst frame.

detection, chromatic dispersion (CD) compensation, and clock recovery. A double-correlation based burst frame synchronization algorithm is adopted, provides a reliable and robust burst detection [15, 16]. The TFDM burst frame for US transmission, as shown in Fig. 2(c) includes a guard band, Rx settling, and synchronization, with the guard band used for separating adjacent burst frames and allowing for transmitter (Tx) turn on/off.

Experimental Setup

The experimental setup for the proposed TFDM coherent PON is shown in Figure 3. Two ECLs are used as light sources at the OLT side - one generates DS TFDM signals through a coherent driver modulator (CDM), while the other provides the OLT receiver's LO for US signal detection. The output of the ECLs is also used to provide optical master tones for injection locking at the ONUs. The experiment uses a 50 km fibre link and a 1x32 passive optical splitter for the optical distribution network (ODN). At the ONU end, a multiport tunable optical filter (TOF) separates the DS TFDM signals and the two optical tones. The DS TFDM signals are detected by a coherent homodyne receiver using OIL LO, and the US TFDM signals are transmitted through another OIL setup coupled to a CDM. Both DS and US signals are processed through offline DSP codes. The optical spectrums of the DS (broadcast) and US (burst) TFDM signals are shown in the insets of Figure 3. Off-the-shelf discrete components are used in the experiment for demonstration, but advanced photonic integration platforms can combine these components to achieve low-cost commercial products.

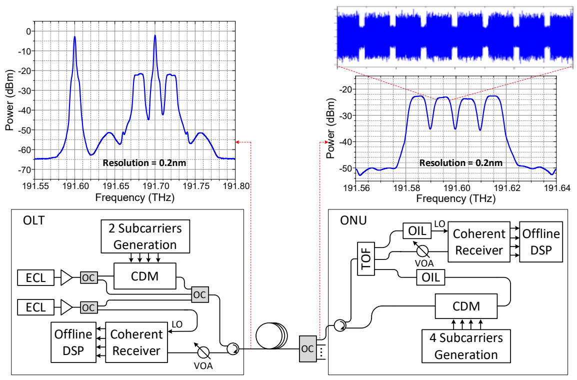

Fig. 3: TFDM coherent PON experimental setup.

Results and Discussions

To demonstrate system functionality and performance of the proposed TFDM coherent PON architecture with remote optical carrier delivery, bi-directional transmission tests has been performed through the 50 km/32 split ODN. System performance for DS transmission in

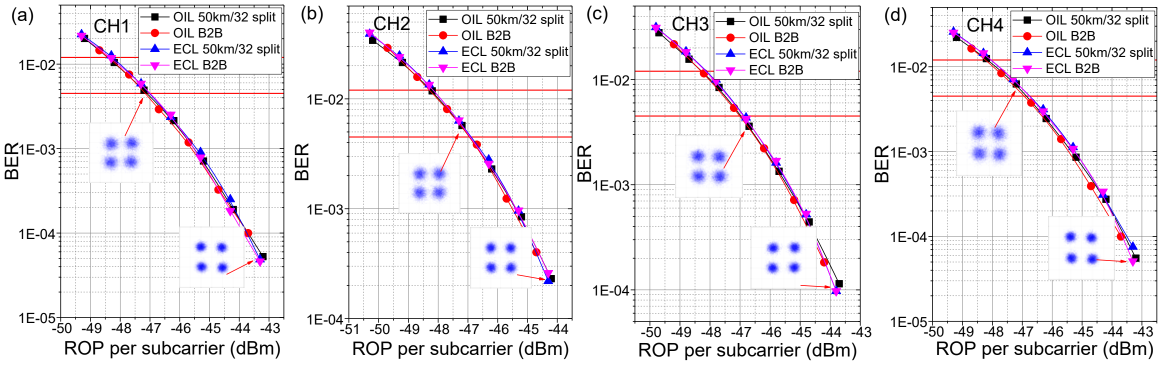

Fig. 4: US TFDM burst transmission BER versus ROP per channel results: (a) CH1; (b) CH2; (c) CH3; (d) CH4.

continuous mode, with injection locked FP-LD used as LO for ONU receiver has been previously reported [9] with minimal performance degradation compared with an ECL based system and will not be repeated here. This work will focus on US burst transmission.

Different symbol lengths are tested for burst synchronization in US transmission using TFDM burst signals. Double-correlation patterns are selected with symbol lengths of 256, 128, 64, 32, and 16, corresponding to time periods of 40.96 ns, 20.48 ns, 10.24 ns, 5.12 ns, and 2.56 ns respectively. Experiments show that a symbol length larger than 32 (5.12 ns) is needed for reliable burst detection. Following experiment use a synchronization pattern of 256 symbols (40.96 ns) and an Rx setting pattern of 512 symbols (81.92 ns) in the TFDM burst signals.

Using an OIL-based ONU Tx laser enabled by the remotely delivered optical tone, bit-error-rate (BER) versus received optical power (ROP) per channel results for US burst TFDM signals are shown in Fig. 4(a)-(d). The results include both fibre transmission (50 km/32 split) and back-to-back (B2B) cases, as well as the BER performance of the four subcarriers using regular ECL as Tx laser in comparison. Similar to the DS broadcasting results, the US burst transmission using the proposed OIL-based transmitter exhibits negligible performance degradation at both the staircase hard-decision (HD) forward error correction (FEC) threshold (BER=4.5E-3) [17] and concatenated soft decision (SD) FEC threshold (BER=1.2E-2) [18], compared with the traditional ECL-based transmitter.

The proposed OIL-based system has an additional benefit of frequency locking the ONU Tx and Rx LO to the OLT light sources, resulting in minimal optical frequency offset between them. In comparison, a regular ECL-based system has a much larger CFO of around 0.34 GHz as shown in Fig. 5(a), making signal recovery impossible without CFO compensation. Where the proposed OIL-based system has a residual CFO of only 0.12 MHz, which enables simplification of the Rx coherent DSP by removing the CFO compensation process without significant performance degradation. Fig. 5(b) shows BER performance of the OIL-based system without CFO compensation in both DS and US burst transmissions. Compared to the ECL-based system with CFO compensation, the OIL-based system offers similar performance, but with significant Rx DSP complexity simplification and ONU hardware cost savings.

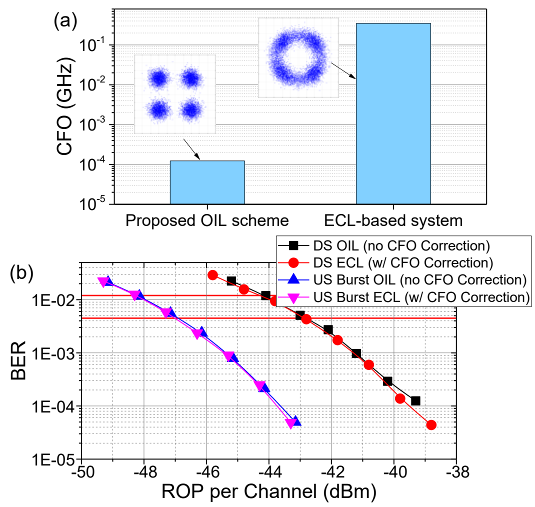

Fig. 5: (a) Residual CFO for proposed OIL scheme vs. regular ECL-based system; (b) BER vs. ROP per channel for proposed OIL scheme without CFO correction compared with regular ECL-based system with CFO correction.

Conclusions

In this study we introduce a novel TFDM coherent PON architecture that features innovations in both hardware and DSP simplification, to enable cost-effective implementations through remote master tone delivery and OIL. System functionality was evaluated through upstream burst transmission, which showed nearly identical performance compared to a traditional ECL-based system. Furthermore, the system CFO was minimized by utilizing frequency locking, enabling the removal of the CFO compensation process from the Rx coherent DSP without compromising system performance.

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