Lightwave Centralized WDM-PON System at Symmetric Rate of 10Gbit/s Employing Cost-effective Directly Modulated Laser

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Abstract: We demonstrate the first lightwave-centralized WDM-PON operating at symmetric rate of 10Gbit/s using cost-effective directly modulated lasers to generate downstream and provide upstream OOK/OFDM-QPSK signals using a re-modulation scheme by an intensity modulator.

Introduction

Compared to time division multiplexing passive optical network (TDM-PON) with complex scheduling algorithms and framing technology, wavelength division multiplexed (WDM) PON has been proposed as a potential solution to meet the ever-increasing demand of large capacity, low latency, and high security for next generation optical access network [1, 2]. Moreover, unlike long haul and metro networks where higher cost can be tolerated and absorbed by the service and volume, access applications require low-hardware cost and low-operation expense to make the transmission technology viable. Consequently, directly modulated lasers (DML) can be used in cost-sensitive optical links due to lower cost, compact size, low power consumption, and high output power characteristics when compared with other transmitter sources using external modulators (EM), such as electro-absorption modulators (EAM) or Mach-Zehnder modulators (MZM) [3, 4]. Additionally, wavelength reuse is attractive scheme to reduce the cost of WDM-PON systems [4-7]. In some of proposed schemes, downstream and upstream signals were modulated in different formats in order to avoid crosstalk such as downstream DPSK and upstream OOK signals [7]. Nevertheless, DPSK modulation requires extra components for the de/modulation of the downstream signals, which may increase the expense of the network. For symmetric WDM-PON system, one of the possible solutions is using reflective semiconductor optical amplifier (RSOA) to re-modulate the downlink signal. However, the data rate is 1.25Gbit/s due to the limitation of the RSOA [8].

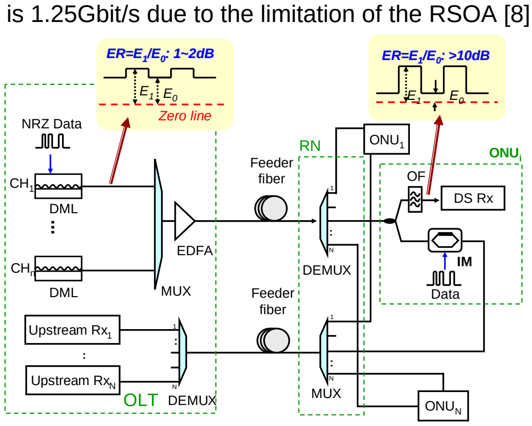

Fig.1: Proposed WDM-POM architecture. DML: directly modulated laser. DE/MUX: optical de/multiplexer. OF: optical filter. IM: intensity modulator.

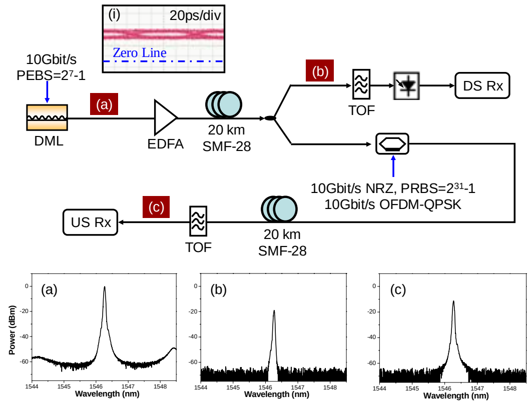

Fig. 2: Experimental setup and received optical spectrum (0.01nm resolution).

In this paper, we propose and experimentally demonstrate a symmetric WDM-PON architecture operating at 10Gbit/s by that exploits the DMLs to trade bandwidth-efficiency for power-efficiency downstream transmission over 20km SMF-28 and re-modulated in OOK and OFDM-QPSK formats for uplink.

The principle of proposed architecture

The principle of the proposed WDM -PON architecture is illustrated in Fig. 1. The optical line terminal (OLT) contains *N* directly modulated lasers (DML), biased at an operating point that is notably higher than the threshold in order to generate high output power. An optical multiplexer (MUX) is employed to combine the WDM channels, with the aggregate signal sent into the feeder fiber for downstream transmission. In the remote node (RN), an optical de-multiplexer (DEMUX) separates the WDM channels for delivery to each optical network unit (ONU). The downstream signals are passed through a 3dB coupler, with one coupler output fed to a downstream receiver (DS RX). One main benefit to use the narrowband filter is that the ER of the optical signal after transmission from the OLT to ONU is still low; therefore it can be re-modulated [9]. The second output is used to realize the upstream link by re-modulation of the downstream via an intensity modulator (IM) to carry a 10Gbit/s OFDM-QPSK or NRZ-OOK signal; this would not be the case for 10Gbit/s OOK downstream transmission, for example. Consequently, a symmetric WDM-PON with centralized lightwave architecture is realized because there is no additional light source in the ONU.

Experiment

The experimental setup is exhibited in Fig. 2. In the central office (CO), a commercially available 1546.6 nm DFB laser is directly modulated at 10Gbit/s using a

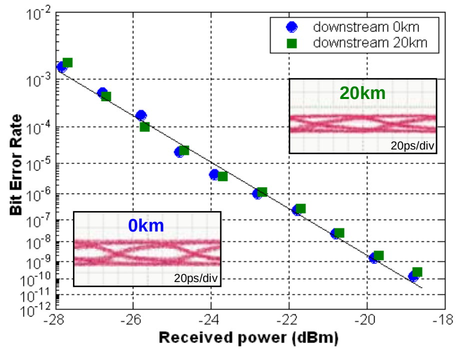

Fig. 3: BER curves and the corresponding eye diagrams and the constellations for downlink 10Gbit/s signals.

pure pseudorandom binary sequence (PRBS) with word length of 2^7-1 which is generated from a commercial pattern generator. The DFB laser was biased at 63mA to produce 6.5dBm average power. The optical spectrum with 0.01nm resolution and the eye diagram with 1.2dB of ER at the output of DML are shown in Fig. 2 as inset (a) and (i). After an EDFA, the CML signal is fed to 20km SMF-28 with 4dBm launched power. The demultiplexed downstream traffic is split by a 3-dB optical coupler. One coupler output is delivered to the DS Rx, while the other is prepared for upstream transmission via re-modulation to a 10Gbit/s signal. Before the DS Rx, a TOF with 3dB bandwidth of 0.5nm is used to reduce amplified spontaneous emission (ASE) noise from the EDFA and enhance the ER. The monitored optical spectrum for down- and upstream over 20km of SMF-28 is present in Fig. 2 (b) and (c).

For upstream link, one IM is employed to re-modulate the downstream signal at 10Gbit/s. In this investigation, two modulation formats are utilized, one is NRZ with PRBS of 2^{31}-1 and the other is OFDM-QPSK signal. The OFDM signal is generated offline and uploaded into a Tektronix AWG7102. QPSK is used for baseband symbol mapping and a 1.6 ns cyclic prefix per OFDM symbol is applied. In the upstream receiver, the OFDM-QPSK signal is filtered by a 0.5nm optical filter, directly-detected by a 20-GHz photo-detector, and sampled by a Tektronix real-time oscilloscope (TDS6154C) at 2.5Gsample/s. All subsequent digital signal processing work was done off-line.

For downstream signals over 20km SMF-28 transmission, the receiving sensitivity for BER equals to 1.4×10^{-10} is -18.8dBm. As shown by Fig. 3, a comparison with back-to-back (0km) results reveals that there is no significant power penalty incurred on the 20km transmission link. Fig. 4 and 5 illustrates the results for re-modualted upstream OOK and OFDM-QPSK signals, respectively. Since the ER of downstream signal is low (~ 1.2dB), the signal can be re-modulated in OOK format by IM. From Fig. 4, it can be seen that the eye diagram is clean and open after 10Gbit/s OOK re-modulation even the downlink signal is intensity modulated format. There is a 2dB power penalty after upstream 20-km transmission due to the shape change of the signal as shown in Fig. 4. Fig. 5 plots the electrical spectrum following re-modulation of the downstream signal with and without 10Gbit/s NRZ data, showing the frequency-domain coexistence of the upstream and downstream traffic. The inset constellations in Fig. 5 shows the OFDM-QPSK signal at back-to-back and after 20km of SMF-28.

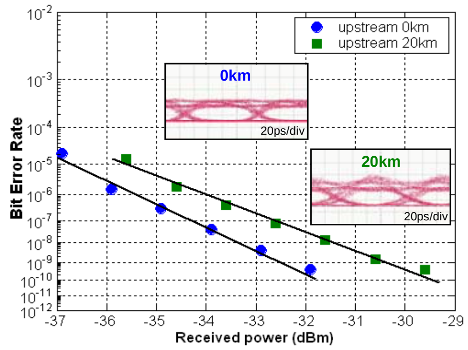

Fig. 4: BER curves and the corresponding eye diagrams and the constellations for uplink 10Gbit/s OOK signals.

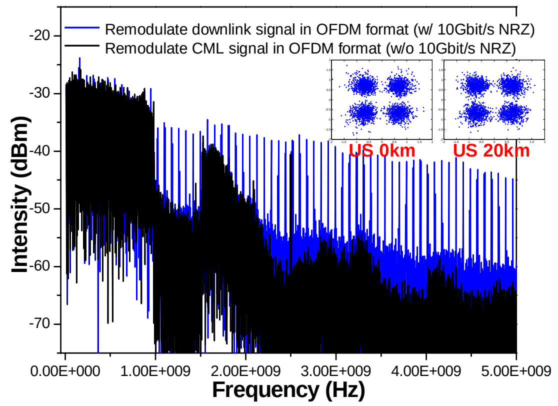

Fig. 5: Received electrical spectrum of re-modulated signal for upstream OFDM based transmission.

The BER value before and after transmission is 2×10^{-4} and 8×10^{-4}.

Conclusions

We proposed and demonstrated a cost-effective, data symmetric, and centralized-lightwave WDM-PON architecture employing a directly modulated laser as the downstream transmitter. Using this scheme, we have successfully transmitted 10Gbit/s downstream signals generated by a DML over 20km SMF-28 fiber, obtaining a negligible power penalty after 20km of transmission. For the upstream link, downstream signals were re-modulated to a 10Gbit/s OOK stream or OFDM-QPSK signal by an intensity modulator based on the low ER of downlink signal. We have also shown that the power penalty for the re-modulated OOK upstream signals is about 2dB after 20km SMF-28 transmission. The results also illustrate the feasibility of OFDM uplink transmission. Because the proposed WDM-PON system is a data symmetric system and employs low-cost DMLs and fewer optical components, it can provide enhanced system reliability at lower component cost.

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