Bidirectional 10 Gbit/s long-reach WDM-PON using digital coherent receivers

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Abstract: Bidirectional transmission at 10 Gbit/s using 3.125 GBaud PDM-QPSK over 100 km of SMF is investigated. We observe no penalty for transmission of 10 GHz spaced channels. Preamplification improves the receiver sensitivity from -45.9 dBm to -53.0 dBm.

OCIS codes: (060.4510) Optical Communications; (060.1660) Coherent Communications.

1. Introduction

In this paper, we investigate the feasibility and advantages of digital coherent receivers in access networks by experimentally evaluating the efficacy of a wavelength division multiplexed long-reach passive optical network (LR-WDM-PON) with bidirectional transmission. In a conventional LR-PON, 10 Gbit/s transmission over 100 km standard single mode fiber (SMF) with a passive 1:1024 way split is acheived using midspan repeaters or transponders followed by direct detection receivers [1]. However, digital coherent receivers are significantly more sensitive than their direct detection counterparts and can increase the loss budget of a PON such that the LR-PON configuration can be implemented without the need for midspan repeaters. In addition, digital coherent receivers are intrinsically spectrally efficient due to frequency selectivity, as well as phase and polarization diversity. As such, increased channel densities, higher data rates and greater transmission distances can be achieved with a greatly reduced network complexity. Thus, using coherent receivers in an LR-PON, a 100 km access network can be implemented that, whilst making the metro network redundant as in a conventional LR-PON architecture, furthers the real-estate and maintenance savings by relocating all equipment to easily serviceable locations; the optical line terminal (OLT) and the optical network units (ONU), shown schematically in Fig. 1.

Although there have been several investigations into coherent access technologies, these have historically implemented coherent detection to take advantage of frequency selectivity [2]. More recent investigations have additionally focused on the sensitivity benefits of coherent detection but without fully utilizing the frequency selectivity [3]. Here, we utilize all the gains afforded by coherent reception, and implement a bidirectional 5-channel (3 downstream, 2 upstream) LR-WDM-PON. We believe that this is the first time the LR-PON operating at 10 Gbit/s has been demonstrated in a bidirectional configuration without the use of midspan repeaters.

2. Experimental Configuration

To experimentally emulate bidirectional transmission in an LR-PON, we created two separate transmitters; as shown in Fig. 2. we modulated 3.125 GBaud QPSK onto CW light provided by an external cavity laser (ECL). This modulated signal was split using a 50% coupler, and one arm was sent to a passive delay line consisting of 10 m of SMF. The second arm was sent to a mach-zehnder intensity modulator (MZM), which was driven at 10 GHz between $\pm v_\pi$. This generated two new frequencies at the central channel frequency $\pm$10 GHz, plus additional harmonic frequencies with amplitudes suppressed by 30 dB. By adjusting the modulator bias, we found that we could suppress the carrier frequency by 35 dB. Upon recombination of the two arms, we obtained three 10GHz spaced carriers where the central channel carried information decorrelated from the outer channels. The signal was then polarization division multiplexed (PDM) through the use of a passive delay line stage, before being amplified and transmitted. The generation of 3.125 GBaud PDM-QPSK corresponds to 10 Gbit/s data transmission plus a 25% overhead reserved for forward error correcting codes (FEC) such as those in [4], which correct bit error rates (BER) up to 2×10^{-2} to below 10^{-15}.

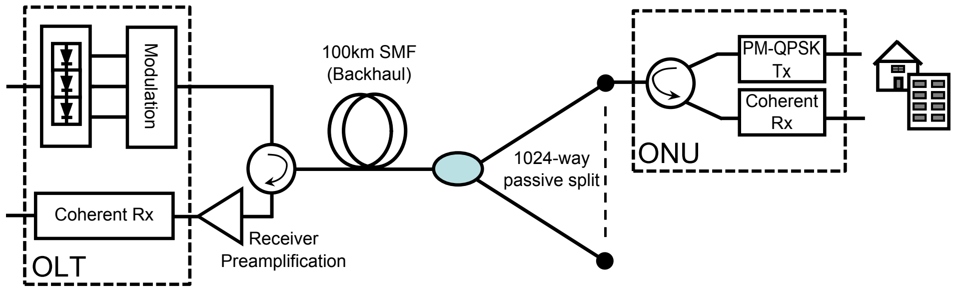

Fig. 1. LR-PON configuration, in which no inline amplifiers are required.

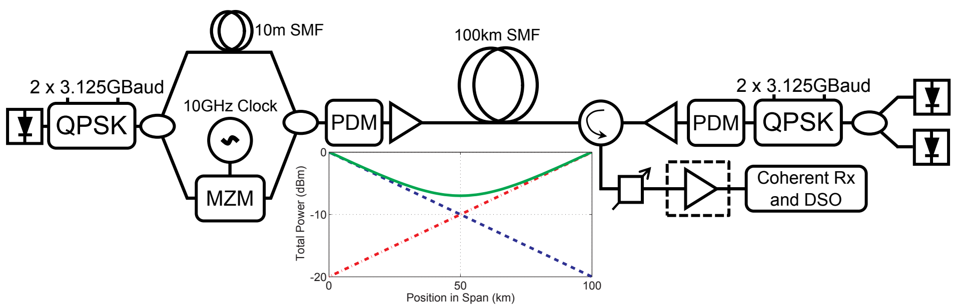

Fig. 2. Bidirectional LR-PON experimental configuration; the power loss due to splitting in the distribution network is emulated by a variable optical attenuator (placed directly before the receiver as we are not evaluating the access span). The MZM is driven at 10 GHz to generate 20 GHz spaced subcarriers. In the case that five channels are required for downstream only experiments, the upstream is combined with the downstream comb before the span. The subplot shows the power at each point in the fiber for any two neighbouring channels in bidirectional transmission at 0 dBm.

The upstream portion of the PON was generated by modulating the output from two ECLs, which had a frequency spacing of 10 GHz and a fixed offset from the downstream channels of 5 GHz. Similarly to the downstream signals, these two upstream channels were polarization multiplexed with a passive delay line stage before being amplified and sent to the fiber; counterpropagating to the downstream signal. The use of a recirculator before the receiver routed the downstream signal to the coherent receiver, where the central channel was demodulated.

Due to the symmetries of a PON, there are only subtle differences between the upstream and downstream configurations. As such, the downstream configuration was considered to be the upstream for the upstream transmission experiment. Here, the receiver was preamplified using a single EDFA. (The use of an EDFA is considered economically viable for the upstream as it amplifies all channels before an OLT whereas, for the downstream, one EDFA is required per ONU.) For both configurations, the signal was detected using a phase and polarization diverse digital coherent receiver before digitization by a digital sampling oscilloscope (DSO) and downsampling to 6.25 Gsamples/s (2 samples/symbol). The constellation was recovered offline in Matlab using digital signal processing, as in [5]. The BER was measured over 2^{17} symbols. The LO laser was provided by a fourth ECL, amplified to 15 dBm via an EDFA and tuned to the central channel frequency.

The maximum split ratio and the maximum transmission distance can be specified by the loss budget; the sum of all losses incurred between the OLT and an ONU. Experimentally, the loss budget is the sum of the total span attenuation (typically 0.2 dB/km) and the attenuation applied at the receiver.

3. Experimental Results and Discussion

These experiments have investigated the performance benefits of preamplified coherent reception, and evaluated the impact of reflections and additional noise incurred in bidirectional transmission. The channel spacings have been fixed at 10 GHz for the upstream and downstream configurations, with a 5 GHz offset between counterpropagating channels. Fig. 3(a) shows the impact of increased transmission power on receiver sensitivity in bidirectional transmission. For the

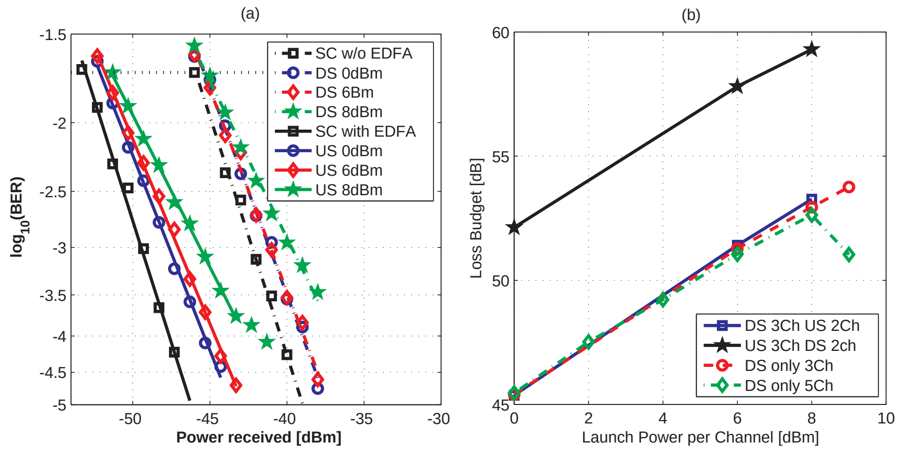

Fig. 3. (a) Sensitivity measurements for single channel (SC), downstream 3-channel with 2 upstream interfering channels (DS), and upstream 3-channel with 2 downstream interfering channels (US) for different launch powers. The single channel measurements are shown with and without preamplification. All US measurements are with a preamplified receiver. (b) Loss budget at the FEC limit (BER=2×10^{-2}) for different transmission powers in the case of downstream only (5-channels and 3-channels) and the bidirectional US and DS configuration.

case of downstream transmission (receiver at the ONU), we find that, compared with the single channel configuration, nonlinear penalty is incurred when the transmission power is above 8 dBm per channel. However, at the FEC limit, 2×10^{-2}, we do not see a significant penalty. This is highlighted in Fig. 3(b) where the loss budget is compared with the launch power per channel for this configuration.

For the upstream configuration, Fig. 3(a) shows a sensitivity benefit due to preamplifying the receiver of 7.1 dB. This results in a sensitivity of -53 dBm (4 photons/bit).

4. Conclusions

We experimentally determined the feasibility of a bidirectional LR-PON operating at 10 Gb/s per wavelength, by transmitting 3-channel downstream (2-channel upstream) WDM-PDM-QPSK at 3.125 GBaud over 100 km. In addition, we evaluated the sensitivity benefit of preamplifying the coherent receiver, which provided a sensitivity gain of 7.1 dB to -53 dBm (4 photons/bit).

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