Single Feeder Bidirectional WDM-PON with Enhanced Resilience to Rayleigh-Backscattering

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Abstract: We report a system demonstration of 6dB-enhanced tolerance to distributed reflections for WDM-PONs using commercial 1.25Gb/s SFP reflective transceivers. The scheme, based on 8B10B-coding and high-pass electrical filtering, works with CW or 10Gb/s downstream seeding.

OCIS codes: (060.2330) Fiber optics Communications; (060.2360) Fiber optics links and subsystems

1. Introduction

In WDM Passive Optical Networks (PONs) colourless terminals should be implemented at the Optical Network Units (ONUs). These usually encompass reflective modulators that are fed either by CW or by a modulated optical downstream signal. Such an architecture is usually indicated as single feeder loop-back WDM PON, and allows for flexible and cost effective deployment. However its performance is severely constrained by reflections occurring both along the feeder fibre (Rayleigh back-scattering) and at fixed points (e.g. connectors). Those reflections originate in-band coherent crosstalk, which is detrimental for the system operation. Because of the typical power unbalance between upstream and downstream, the reflection-induced penalties are particularly critical for the upstream transmission, where the crosstalk produces Optical Beating (OB) noise on the uplink signal. Therefore the optical signal-to-crosstalk-ratio (SCR) is a critical parameter for system design. It was reported that the SCR value can be maximised by setting the gain of the reflective modulators to quasi-compensate for the one-way link losses [1]. Although maximizing the SCR minimises the OB noise, it might not be enough to ensure error-free transmission. Several solutions were proposed to increase the system tolerance to in-band reflections. Some methods aim to reduce the coherence time of the feeding signal, so that the amplitude of OB is minimised. This can be obtained by external phase modulation or by data-dithering of the upstream transmitter. However, both the phase modulation and the dithering should be applied out-of-band, i.e., at frequencies higher than the signalling rate (e.g. 5 GHz for 1.25 Gb/s signals) [2]. Other approaches exploit the limiting amplification in Semiconductor Optical Amplifiers (SOAs): indeed, the SOA limiting amplification realizes a high-pass filter, reducing the intensity noise by OB which is mostly at low-frequencies [3]. On the other side high-pass electrical filtering approach has been also proposed after photo-detection [4] at the Central Office, and was found really effective when combined with proper line coding, [5]: as the beating noise extends on a spectral region of a few MHz, an aggressive DC-blocking can largely suppress it. This approach has also another benefit: the receiver optimal threshold becomes independent on the crosstalk level. However, in order to avoid strong inter-symbol interference (ISI) and base-line wander, this approach requires that the data stream is DC balanced, e.g. by using 8B/10B line coding (which, by chance, is already available in Gb-Ethernet) [5]. This approach therefore does not alter the WDM-PON architecture; it does not require additional devices (e.g. phase modulators, SOAs,…), and is implemented by using low-cost and well-established components (the 8B10B encoder/decoder and an ad-hoc high-pass electrical filter). It is therefore a completely seamless approach.

Here we report the first demonstration, to the best of our knowledge, of a realistic WDM-PON system exploiting the combined action of high-pass filtering and line-coding. In a system demonstration obtained by using commercial reflective modulators packaged in standard SFP transceiver modules, we prove the effectiveness of this technique both by using CW and 10 Gb/s feeding signals.

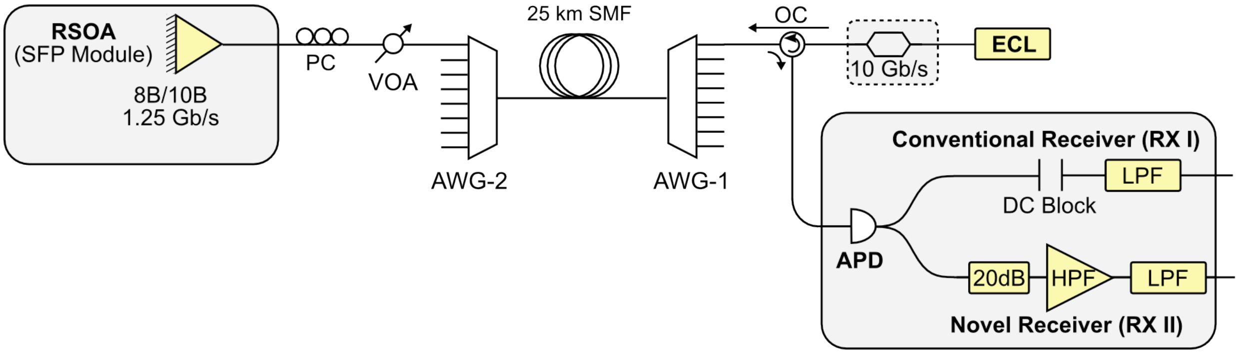

Fig. 1 Experimental setup. ECL: External Cavity Laser; OC: Optical Circulator; AWG: Arrayed Waveguide Grating; VOA: Variable-Optical Attenuator; PC: Polarization Controller; R-SOA: Reflective Semiconductor Optical Amplifier; APD: Avalanche Photodiode; HPF: High Pass Filter; LPF: Low-Pass Filter

2. Experimental Setup

We realized a WDM-PON system of 25 km reach, as sketched in fig. 1. At the Central Office, a tunable laser generated the feeding signal (λ = 1551.74 nm). The feeding signal was sent to a 3-port optical circulator (OC) with 0.8 dB insertion loss (IL), and then launched into the feeder fiber (SMF, 25 km, 6 dB IL) through a WDM multiplexer (AWG-1). A second AWG (AWG-2) routed the feeding signal to the ONU. Both AWGs had same specifications (200 GHz FSR, 50 GHz bandwidth, 3dB IL). The ONU was equipped with a small form-factor pluggable (SFP) commercial transceiver containing a Reflective SOA and a PIN photodiode having -18 dBm sensitivity. The reflective SOA had 3 dBm output saturation power, 20 dB optical gain and 2 dB unsaturated polarization dependent gain. The SFP module guaranteed error-free operation for injection power levels between -5 and 0 dBm. When injected with a CW light, the SFP produced NRZ signals with 7 dB extinction ratio. The SFP module was driven by a 1.25 Gb/s pulse pattern generator (.25 V peak-to-peak), programmed to produce either an uncoded 2^7-1 PRBS sequence or the equivalent sequence coded using 8B10B. The transceiver was connected to AWG-2 by means of a variable optical attenuator (VOA) to emulate losses from a passive splitter, and a polarization controller (PC) to maximise the beating noise between the upstream signal and the Rayleigh-Backscattered feeding signal. At the central office (CO) the upstream receiver was implemented by an APD photodiode providing a differential output (two identical outputs, but inverted). One of the outputs was used to realize a conventional AC-coupled receiver, comprising a DC block (7 kHz cut-off) and a matched 933 MHz Bessel low-pass filter. We refer to this output as "Receiver I". The second output was connected to two cascaded filters. The first was a high-pass-filter (HPF) having 10 MHz cut-off. It rejects the beating noise generated by the interference of the back-scattered light and the upstream signal. The signal was then further filtered by another Bessel low-pass filter (933 MHz bandwidth). We refer to this filtering system as "Receiver II" in the following. Due to the lack of an HPF, the first filtering stage was implemented by a 1 GHz bandwidth electrical amplifier with 10 MHz low-frequency cut-off. By using an electrical attenuator and by controlling the amplifier gain we set the electrical power of the two receivers at the same level, in order to fairly compare the signals obtained by the two receivers.

In a first experiment, we fed the R-SOA with a CW signal. We set the VOA in order to inject the R-SOA with power levels down to -17 dBm (corresponding to 18 dB total link losses). In this condition, the R-SOA was operated far from the saturation (it provided about 20 dB gain) and we measured a signal to noise ratio of 17 dB. We remark that the crosstalk was due mainly to two sources: the first was the Rayleigh backscattering of the feeding CW (carrier-BS), which co-propagates with the uplink signal. The second was the backscattering of the uplink signal which re-entered the R-SOA, was amplified, and then was launched back through the feeder fiber (signal-BS) [3].

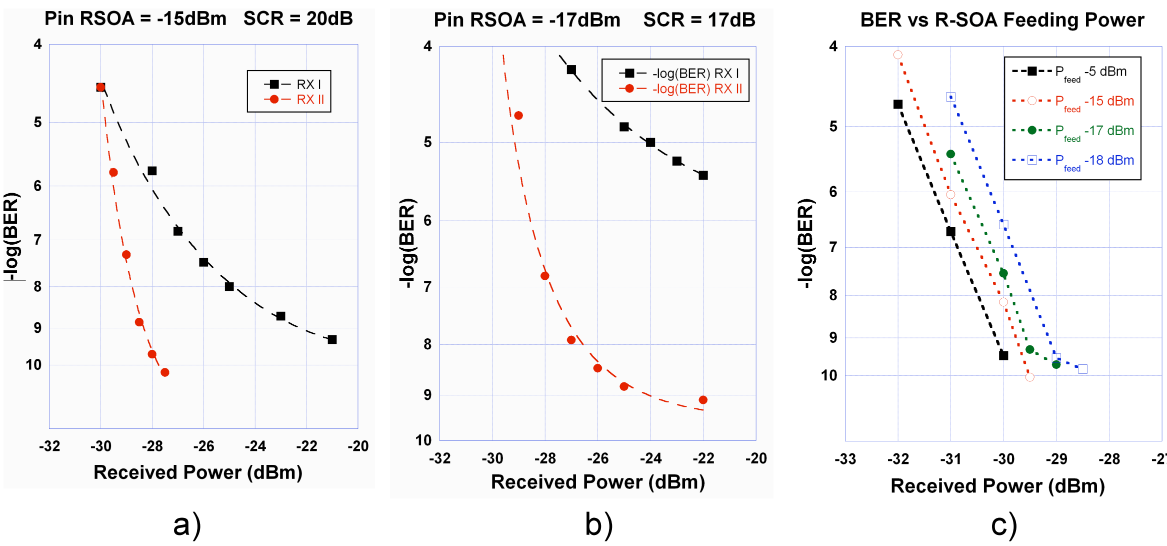

Fig. 2 a-b) Uplink performance at different SCR values. c) BER vs feeding power (CW) w/o added crosstalk for the R-SOA SFP module employed in the experiment

We report in fig. 2 the Bit Error Ratio (BER) measurements obtained on the uplink signal by using the two receivers for two different injection power levels at the RSOA input (-15 and -17 dBm, for SCR of 20 and 17 dB respectively). We remark that all BER measurements were taken using a receiver with fixed decision threshold, determined in the crosstalk-free operation mode. As we can see, when using the receiver I the system performance is limited and we clearly see a BER floor at 10^{-10} and 10^{-6} for -15 and -17 dBm injection power, respectively. On the other hand, when the same uplink signal is received by means of the receiver II, BER values are significantly lower. In the case of -15 dBm injection power, is it possible to achieve almost error-free operation, recovering about 6 dB power penalty at 10^{-9}. However, in the case of -17 dBm injection power, even the receiver II shows a floor tendency (at 10^{-9}). This different behaviour, is due mainly to two effects: the first is the increase of the signal-BS scattering, which is largely increased as now the R-SOA gain exceeds the link losses [1]. Additional penalty arises also because the SFP transceiver requires a high optical injection power (e.g., -5 dBm) to provide optimal operation. For completeness, we also report in fig. 2 c) the BER curves obtained by feeding the SFP module with different power levels. As it can be seen for an injection power of -18 dBm, the SFP shows a BER floor, even without crosstalk.

In a second experiment, we assessed the performance of the Receiver II when the feeding signal was also modulated. In this case, we inserted a Mach-Zehnder modulator driven by 1.25, 2.5, and 10 Gb/s data to generate the downstream signal. In order to allow the SFP to cancel the downstream modulation, we reduced the downstream extinction ratio to 3 dB, and increased the launch power, in order to feed the SFP module with -3 dBm optical power. We note that in this case the SFP module was injected with optimal power (see fig 2-c). In addition, as the R-SOA was highly saturated (providing about 5 dB gain), the system was mainly affected by carrier-BS (SCR = 20 dB). As in the previous case, we took uplink performance measurements by setting the uplink channel polarization to achieve the highest possible OB noise. Here if the downstream signal was modulated at 1.25 or 2.5 Gb/s, we didn't get any significant performance improvement by employing 8B10B code and the HPF. However we observed a marked improvement when the downstream was a 10 Gb/s signal. In that case using a PRBS downlink stream, Receiver I showed a BER floor at 10^{-6}, while Receiver II gave a much lower floor (at 10^{-9}). This BER value was obtained for receiver power levels around -18 dBm (+8 dB power penalty compared to the CW feeding). Again, the system sensitivity was further improved by applying the 8B10B encoding also on the downstream data: this coding allows to minimize the spectral overlap of the back-scattered and the uplink signals. In this case (fig. 2-b), both receivers show better performance. However, while RX I still exhibits a BER floor, RX II is by far more effective, having around -26 dBm sensitivity (2 dB power penalty in respect to the CW feeding system). In fig. 3-c we also report eye diagrams of the uplink signal detected simultaneously with RX I and II, showing the effect of the application of the line-code also on the downstream case.

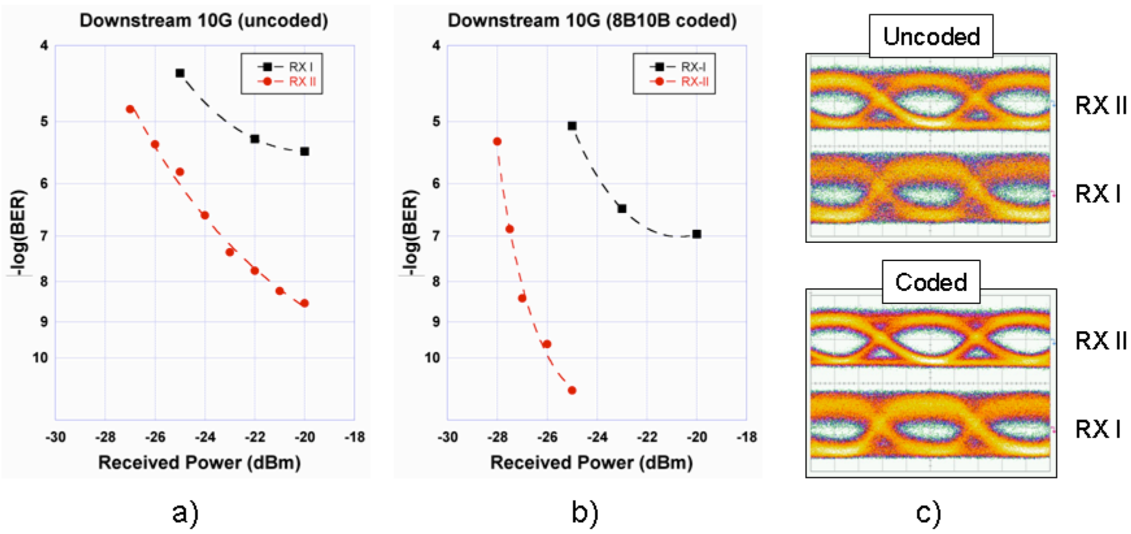

Fig. 3. Uplink performance with modulated feeding signal. a) with no coding in downstream; b) with 8B10B coding in downstream. c) eye diagrams recorded with the two receivers w/o and w/ coding in downstream.

3. Conclusions

We experimentally demonstrated a single-feeder bidirectional WDM-PON with colourless reflective modulators with enhanced tolerance to impairments induced by Rayleigh back-scattering. The enhancement is achieved by using 8B10B coding (already available in GbE) and ad-hoc post-detection high-pass filtering in the uplink. The implementation of this technique does not require additional electro-optical components in respect to typical WDM-PON architecture. The technique has been demonstrated by using commercial reflective modulators in standard SFP transceivers. It is effective both with CW and modulated remote feeding signals, provided that the network operates asymmetrically (e.g. 10/1.25Gbs) and that a DC-balancing line code is also applied at the downstream signal.

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