GPON reach extension to 60 km with entirely passive fibre plant using Raman amplification

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Abstract *We describe a purely-passive GPON compatible reach extender using distributed Raman amplification. Operation over 60 km of AllWave fibre at 2.5 Gbit/s is demonstrated with a total loss budget of 43 dB at 1310 nm.*

1. Introduction

Passive optical networks (PONs) are now being deployed in large numbers worldwide and will play an increasingly important role in future broadband access networks. The GPON standard [1] allows for a logical reach of 60 km and 128 addressable ONTs. However, the 28 dB loss budget for Class B+ limits typical GPON deployments to 1:32 split and < 20 km reach. There have been several reports on techniques to extend the reach of PON systems [2-3] and GPON reach extenders have been standardised recently by the ITU-T (G.984.6).

The reach extension approaches considered in G.984.6 require the use of electrically powered units in the field containing optical amplifiers or OEO repeaters, but this is negates some of the advantages of PON systems and may not always be practical or cost effective for operators, particularly in certain environments where there is no electrical powering. Thus, techniques that enable PON reach extension whilst maintaining a totally passive outside plant could be very attractive for network operators. Raman amplification in the transmission fibre is one such technique that could improve the PON loss budget with the addition of suitable pump lasers coupled to the fibre at the central office (OLT). There has been a recent report on such an idea [4] but this system demonstration deviated from the GPON standards in some respects. The authors used a narrow pass band for the upstream channel (< 1 nm) centred at 1350 nm, whereas the narrowest pass band allowed for DFB based GPON is 1300-1320 nm (G.984.5). This wavelength tolerance allows for the use of low cost, uncooled transmitters.

In this paper, we demonstrate distributed Raman amplification in AllWave fibre to enable a system reach of 60 km and total loss budget of 43.0 dB at 1310 nm. Pump wavelengths of 1239 nm and 1427 nm have been used for Raman amplification of both upstream (US) at 1310 nm and downstream (DS) at 1490 nm signals. These pump wavelengths have been selected to ensure compatibility with standard GPON wavelengths whilst reducing unwanted pump-to-signal interactions.

2. Experiment

Fig.1 is a schematic diagram of the experiment, showing a central office (CO) with OLT which is connected to the remote node (RN) by 60 km of low water peak AllWave fibre and optical network units (ONU) at the subscriber premises. The OLT consists of a DFB laser diode (LD) at 1490 nm as the transmitter for the DS signal, 1310 nm APD receiver, a WDM combiner, and two Raman pumps at 1239 nm and 1427 nm, which provide optical pumping for distributed Raman amplification of US and DS signals, respectively. The RN uses only passive optical components: the optical splitter and a band pass filter (BPF). The BPF is used to filter out the residual pump light for 1490 nm receivers at the ONUs. The ONU uses a DFB LD operating 1310 nm transmit US signals.

The 1239 nm pump light, providing counter-propagating Raman gain for the 1310 nm US signal, is generated in a cascaded Raman resonator (CRR) [5]. Laser diodes at 915 nm are used to pump a Yb-doped cladding-pumped fibre laser, whose output at 1100 nm is input to the CRR which consists of Raman fibre and a cascaded grating set to shift the output wavelength up to 1239 nm.

The co-propagating pump providing gain for the 1490 nm DS signal uses two, polarisation

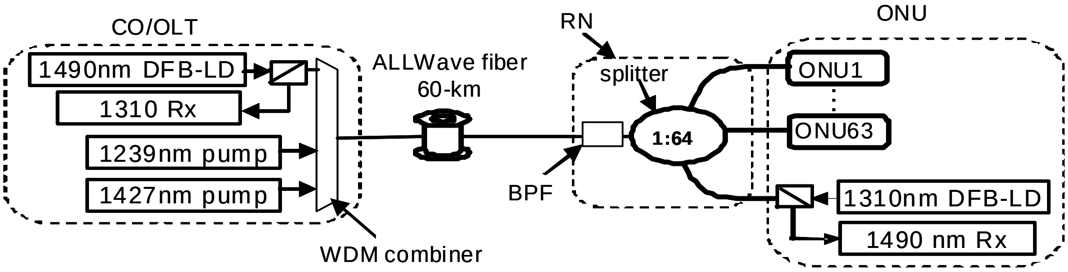

Fig. 1: Experimental set-up for un-powered extender in PON

multiplexed, 1427 nm LDs with RIN < 150 dB/Hz. A pump near 1400 nm would provide the maximum Raman gain efficiency for a 1490 nm signal; however the US 1310 nm signal would be significantly depleted in this case. A design trade-off was made by moving the Raman pump for the DS signal to 1427 nm to minimise depletion at 1310 nm whilst providing enough gain at 1490 nm.

The 1490 nm and 1310 nm LDs located at the OLT and ONU were commercially available un-cooled DFBs with 3 dBm output power. The measured fibre losses at 1310 nm and 1490 nm were 0.317dB/km and 0.21dB/km respectively. The 64-way splitter loss was set to be 20 dB, and the total loss of WDM coupler, connectors and BPF was 4.0 dB. Hence the total link loss budget between OLT and ONU is 43.0 dB and 36.6 dB for US 1310 nm and DS 1490nm signals, respectively.

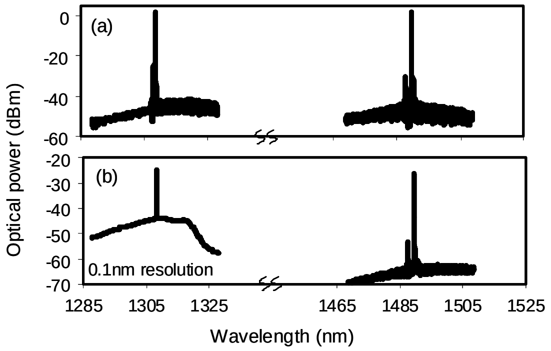

Fig. 2: (a)Input and (b) output spectra for upstream (1310 nm) and downstream (1490 nm) signals

The 1427 nm pump provided 7 dB on-off Raman gain for a power of 370 mW. As shown in Fig. 2b, there is a minimal degradation on OSNR for the 1490 nm signal, because of the relatively high input power in the co-propagating pump configuration. Conversely, the OSNR of 1310 nm signal was degraded (Fig. 2b) due the low input power in the counter-propagating pump configuration. Additionally, the 1310 nm signal was partially depleted by the 1427 nm pumps.

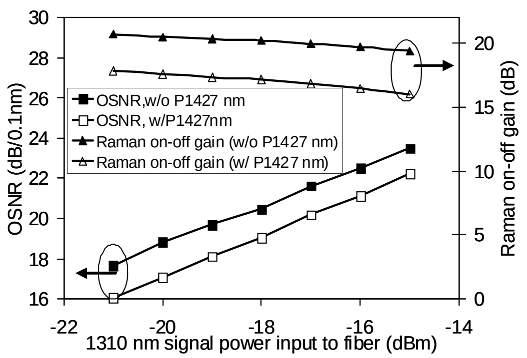

Fig. 3: Raman on-off gains and OSNRs for 1310 signals

Fig. 3 shows the Raman on-off gain and OSNR of the 1310 nm signal as a function of fibre input power with 980 mW of pump power at 1239 nm. The gain of the 1310 nm signal drops by 3.5 dB with the 1427 nm pumps on and there is a resultant OSNR decrease of 2 dB.

3. System results and discussion

The DFB LDs at 1310 nm and 1490 nm were directly modulated at 2.488 Gbit/s (2^{31}-1 PRBS) and transmitted to APD receivers. Fig. 4 shows the bit-error-ratio (BER) performance for US and DS signals with both channels operating through the system simultaneously. It can be seen that there is only about 0.6 dB power penalty for the 1490 nm DS signal, after 60 km transmission with total link loss of 36.6 dB. The power penalty may be caused by chromatic dispersion at 1490 nm. The US BER performance was degraded by as much as 3.6 dB relative to the baseline due to added noise in the distributed Raman amplifier. However, there was no indication of error floors, and error free bi-directional transmission over 60 km fiber with 1:64 split for 1310 nm and 1490 nm signals was achieved at 2.488 Gbit/s.

Although we have demonstrated only continuous upstream BER performance, the performance with burst-mode upstream signals should not suffer any transient effects due to the Raman amplification. We also would expect to see improvements in pumping efficiency with lower loss WDM combiners (currently 2.7 dB at 1239 nm in this experiment) at the OLT

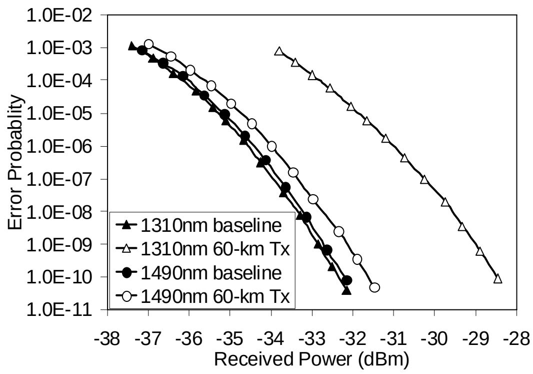

Fig. 4: BER performance of the extended PON systems

4. Summary

We have demonstrated a PON reach extender capable of 60 km reach and 1:64 split ratio using Raman amplification, thus enabling the use of entirely passive outside plant. No error floors were observed in bi-directional transmission with the link losses of 43.0 dB and 36.6 dB for 1310 nm and 1490 nm signals, respectively

We thank David DiGiovanni at OFS Labs for his encouragement and support

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