ONU Optimal Gain and Position of the Distribution Element in Rayleigh-limited WDM and TDM PONs with reflective ONU

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Abstract

The influence of the distribution element position in PONs is reported. Best Crosstalk-to-Signal ratio (C/S) is achieved if it is placed either in the ONU or OLT vicinity with optimum ONU gain depending of the MUX position.

Introduction

Recent developments in PONs propose to employ a reflective structure at the Optical Network Unit (ONU), with centralized seeding light at the Optical Light Termination (OLT) [1-2]. The carrier signal (CW) is then modulated with the upstream data at the ONU and reflected-back in the upstream direction on the same wavelength and fiber. Nevertheless, in this full-duplex single-fiber bidirectional transmission context, Rayleigh backscattering (RB) dominates with respect to others interferences [2]. The aim of this work is the analysis of penalties in the upstream path due to RB effect, in both TDM-PONs and WDM-PONs, with respect to relevant design parameters like the position of the distribution element (coupler or multiplexer, respectively), in order to establish the better location for it, with the ONU gain optimum on each case.

Rayleigh analysis in WDM-PON

In WDM-PON, the MUX separates the wavelength channels, and introducing a fixed attenuation and splitting the RB analysis into two zones: the feeder section ($RB_{OLT\text{-}MUX}$) and the drop section ($RB_{ONU\text{-}MUX}$), Fig. 1.

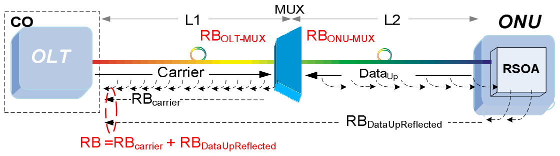

Figure 1. Scenario WDM-PON with MUX at the ODN

A considerable reduction of $RB_{ONU\text{-}MUX}$ received at the OLT is about one order of magnitude smaller (twice the insertion losses of the MUX) than the RB generated by the carrier signal ($RB_{Carrier}$) at the feeder side ($RB_{OLT\text{-}MUX}$). In a similar way, the RB generated by the upstream, reamplified at the ONU and transmitted to the OLT ($RB_{DataUpReflected}$) dominate in the drop side ($RB_{ONU\text{-}MUX}$).

so: $RB_{DataUpReflected} = P_{out\text{-}ONU} \cdot B(1-l_2^2)\cdot(g\cdot l_1\cdot l_2\cdot A)$

where, l_1 and l_2 are the link losses in the feeder and the drop sections, respectively, A is the insertion loss of the distribution element, and with

$$P_{out\text{-}ONU} = P_{carrier}\cdot(g\cdot l_1\cdot l_2\cdot A)$$

The crosstalk, due to Rayleigh at the OLT input is the sum of $RB_{carrier}$ and $RB_{DataUpReflected}$:

$$C = P_{Carrier}\cdot[B(1-l_1^2)+(l_1\cdot l_2\cdot A)^2\cdot g^2\cdot B(1-l_2^2)]$$

with: $$RB_{carrier} = \mathrm{P_{Carrier}}\cdot B(1-l^2)$$

The resulting C/S (or OSRR[-1]) is then:

$$\left[\frac{C}{S}\right] = B\frac{(1-l_1^2)+(l_1 l_2 A)^2(1-l_2^2)g^2}{(l_1 l_2 A)^2 g}$$

The position of the MUX that enhances the system performance for a fixed value of the ONU gain is represented in Fig. 2.

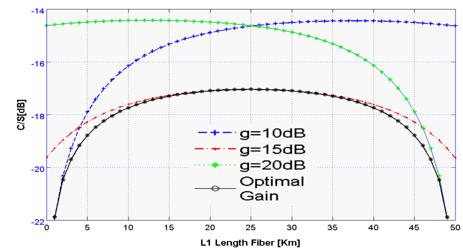

Figure 2. Theoretical (C/S) as a function of the feeder length and ONU gain of 10, 15, 20 dB and optimal value

If the MUX is in the ONU vicinity; ONU gain values about 20 dB are optimum (ONU gain much over this value would produce nonlinear effects, like Brillouin). In contrast, if the MUX is near the OLT, small ONU gain between 10–15 dB improve the upstream BER performance, for lower gain values, other noise sources would have to be taken into account.

Figure 2 shows also the $g_{optimal}$ curve as a function of the MUX position to optimize the C/S ratio, obtained by $\partial(C/S)/\partial g = 0$ (with $l_{total}=l_1 l_2 A$):

$$g_{optim} = \frac{1}{l_{total}}\sqrt{\frac{(1-l_1^2)}{(1-l_2^2)}}$$

Rayleigh analysis in TDM-PON

The scenario for this analysis is shown in Fig. 3. The equations used for it are basically the same at the WDM case, except that now the RB noises from all drop fibres accumulate and the upstream transmission is in burst mode. In such case $RB_{DataUpReflected}$ at the coupler is given by:

$$RB_{Coupler} = \sum_{n=1}^{m} B(1-l_{drop-n}^2)\cdot l_{drop-n}\cdot P_{out-ONUn-Av}\cdot g_n$$

with $l_{drop\text{-}n}$, the losses in the drop fiber to ONU_n and $P_{out\text{-}ONUn\text{-}Av}=P_{out\text{-}ONU}\cdot(OR)$, where *OR* is the time of frame in the time slot assigned by the MAC-OLT to the ONU_n. This value depends on the Rayleigh efective time (for L_{ef}=21,7Km, t_{ef}=108.5us), lower than the GPON time frame of 125us [3-5], so the RB power can be averaged in the frame time.

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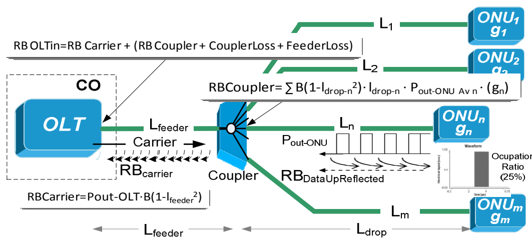

Figure 3. Scenario TDM-PON with Coupler at the ODN

Fig. 4 shows C/S as a function of the position of coupler for occupation ratios of 100% and 25% of of a ONU, with same link losses (15dB) that in WDM case. The results are not very different to the ones for WDM, with some differences. The RB accumulates at the coupler, but the time is distributed, and the overall effect is compensated, depending on the OR and the excess loss. Since the excess loss of the coupler is lower than the MUX, the RB at the feeder side becomes less relevant and the curves become more asymmetrical. Logically, the C/S highly improves at low ORs, since the RB is lower too.

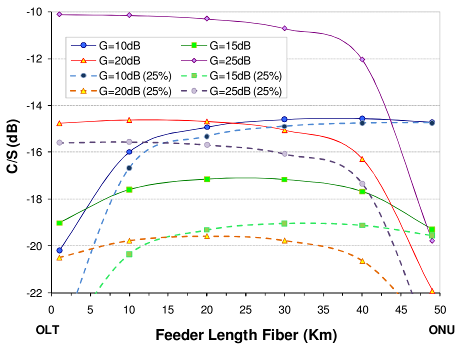

Figure 4. C/S as a function of the feeder length fiber and ONU gain of 10, 15, 20 and 25 dB

Experimental Setup

Figure 5 shows the experimental setup. At the OLT, a tuneable laser was used to feed the ONU at 1550.14 nm, matching the MUX channel. The power applied to the feeder fiber was 0 dBm. The upstream reception was carried out by an APD (sensitivity of -26dBm). An optical filter (BW 34.5 GHz) was introduced before the photo-detection. A variable attenuator was used to obtain the sensitivity curve (Fig. 6). The link was formed by two fiber sections of 25 km, with a total attenuation of 10 dB. A MUX with 5 dB insertion loss was employed as a distribution element.

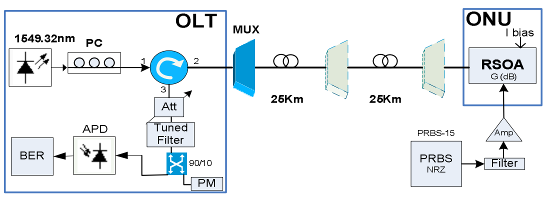

Figure 5: Experimental setup for the measurements

The ONU was formed by a Kamelian RSOA 18-TO-37-08, directly modulated with the upstream data at 1.25Gbit/s, (PRBS 2^{15}-1, ER= 11 dB). The RSOA gain values (10, 15 and 20 dB) was characterized as a function of the bias current (34, 45 and 80 mA). Back-to-back measurement was performed (Fig. 6).

Several measurements were carried out for different positions of the MUX: at the OLT side (L1= 0km, L2= 50km); at the ONU premises (L1= 50 km, L2= 0 km); and at half-way of the link (L1=25 km, L2=25km) (Fig. 6).

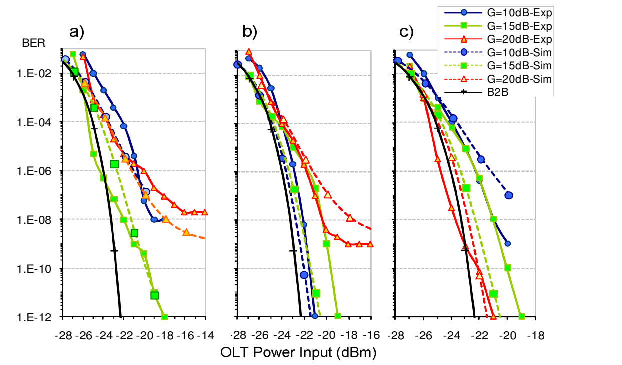

Figure 6. BER measurements for 10, 15 and 20dB of ONU gain with the distribution element a) near at the OLT, b) close to the ONU, c) at half way of the ODN. Experimental and simulate curves.

With the MUX near the OLT, the ONU gain of 10 dB performs the best (1.2 dB penalty). The worse case is for the gain of 20dB, with an error floor at BER = 10^{-9}. This result is due to the greatest influence of the RBreflected at the ONU on the system, with the increased of the ONU gain over the link loss.

At the ONU side, higher amplification improves the system. The penalty for G=20dB is negligible. Here, there is an error floor in the order of BER = 10^{-7} for the lowest gain (10dB), since in this case, the $RB_{carrier}$ is the most limiting, as the upstream signal is weak. The reflected RB is not relevant due to the double attenuation by the MUX and the feeder fiber.

For the MUX located in the middle of the link, the performances are, in general, worse; because the 25 km of fiber on each side are long enough for the RB generation in both of the sections. $RB_{carrier}$ is the most relevant for low ONU gain while $RB_{reflected}$ is for high gain. In this case, ONU gain equal to the link loss is the best (penalty of 3 dB).

Conclusion

We demonstrate that the crosstalk signals vary depending on the position of the distribution element, since they are determined by the length of the fiber and by the ONU gain applied. The results reveal that best C/S is achieved if the distribution element is placed either in the ONU or OLT vicinity. In such case, the ONU gain has a new optimum depending on the position of the distribution element.

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