Optical Amplifier for Optical Burst Switching Networks

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ABSTRACT

In this paper we review recent progress in optical gain clamped Erbium-doped fibre amplifier in burst-mode operation. In particular we focus on the application in optical burst switching networks where physical impairments may occur due to the interplay between burst interval arrival time and intrinsic amplifier characteristics.

Keywords: optical amplifier, gain control, optical network, burst traffic.

1. INTRODUCTION

Optical burst transmission is a promising solution to implement IP traffic over WDM and guarantee payload transparency and efficient bandwidth utilization [1]. At the physical layer the burst transmission may cause impairment to the optical amplifier (OA) which gain varies with the burst traffic and as a consequence signal power transients accumulate in cascaded amplified network. This problem will be obviously increased in a WDM system as the total burst channels power may vary largely at the amplifier and electronic feedback technique generates considerable gain variation after several spans [2].

Optically gain clamping (OGC) technique is a simple, passive and fibre compatible solution that efficiently stabilizes the amplifier gain. We have investigated this technique to stabilize optical burst signal and have noticed a complex behaviour in case of burst sequences with frequency related to the natural device relaxation oscillation frequencies [3,4], with some analogies with extremely low gain laser configuration [5].

In this paper, we review recent progress on the burst amplification. In order to better understand the impact of burst transmission in the optical amplifier dynamics we have collected real traffic from a tailor made testbed [6]. Several scenarios are studied theoretically and excellent performance is obtained using OGC scheme. The interplay between burst arrival time and OGC-OA dynamics is analyzed. The theoretical results rely on a program validated extensively [4,7] and the results represent an reliable picture of OGC-OA performance with burst traffic [8]. In addition experiments were carried out using the collected burst traffic. We simulate a 16 WDM burst transmission to characterize the amplifier dynamics and assess the standard and OGC amplifier in burst mode operation. The peak-to-peak power transients is reduced by four fold for the OGC-OA compared to standard amplifier [9] which proves the effectiveness of the optical gain clamping.

2. REAL BURST DATA COLLECTION

We consider a scenario where several client networks are attached to a single OBS node. At this node packets aggregation and bursts generation are performed. For the client traffic we use real packet traces captured with a tailor-made measurement platform designed to operate at gigabit speed without packet losses and ns-precision in the packet time-stamp measurements.

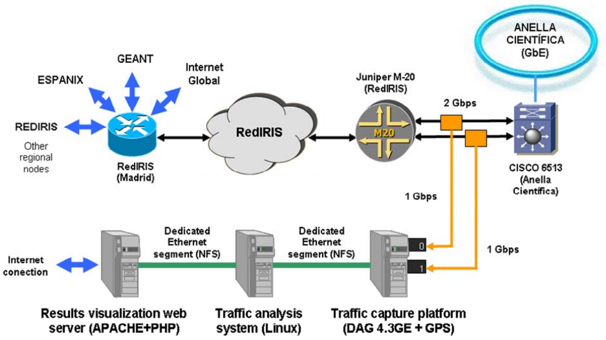

Figure 1. Experimental testbed to collect burst data.

The point of measurement is a pair of Full-Duplex Gigabit Ethernet links (two per each traffic direction) that connects the Catalan R&D network of about 50 Universities and Research Centers with the Spanish R&D

978-1-4244-2626-3/08/$25.00

RedIris network and to the global Internet [6]. A hybrid timer-length threshold burst assembler [10] is used to aggregate the packets; the timer threshold is set to 5 ms and the maximum burst length to 250 kbytes. We assume that the OBS network domain is composed of 30 nodes; the destination of the bursts is therefore obtained aggregating the IP addresses of the packet traces according to the geographical location. The testbed provides a 14-seconds trace of 95 k bursts with burst period varying from 6 μs to 200 μs. The WDM burst stream is composed by uncorrelated data in different time slot. A 1-second long trace is obtained.

3. OPTICAL BURST AMPLIFIER MODELLING

The optical burst amplifier is modelled using a two-level equation to simulate the dynamics of an optically gain clamped Erbium-doped fibre amplifier (OGC-EDFA) [11]. Although the model is simple it was demonstrated that it gives good results compared to experiments and a significant reduction of the computational time. The amplifier has its gain controlled by an optical feedback and can be represented as a laser system. The pump flux is described as a function of laser threshold pump flux which relates as $P_p = x \cdot P_{pth}$ [11]. We assume an optical amplifier with 20 dB gain and 21-m cavity length. The maximum total input power is -1 dBm when all WDM burst channels are simultaneous arriving at the amplifier. The pump power is 15% higher than unclamped amplifier ($x = 1.15$).

In a previous work we have found that if the burst frequency interplay with the characteristics OGC-EDFA relaxation oscillation frequencies (ROF) enhanced oscillations may occur with interplay starting from $\nu_{on}/3$ to about 2 times ν_{off} [7], which corresponds in our case from 7 kHz to 100 kHz interval. In addition a high gain variation may be induced after a few burst sequence [4]. The real data burst distribution fall well within this interval, however different channel will combine in a random mode to generate a total power time variation as stated below.

Fig. 2 show a 3-ms trace of the total input WDM burst data at the amplifier. As can be observed at least two burst channels and no more than 13 channels are simultaneously arriving at the optical amplifier. The average input power is about -4 dBm (8 out of 16 channels). Note that abrupt channel number variation is not seen which could cause significant gain variations [8].

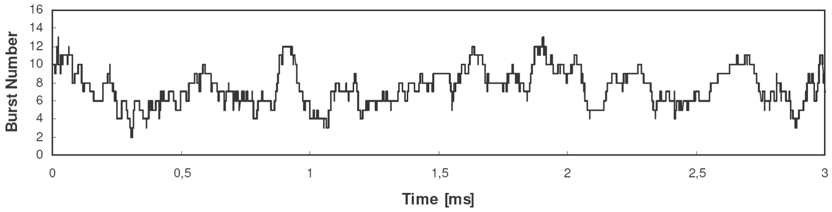

Figure 2. Burst channels along time with -1dBm total input power for 16 channels.

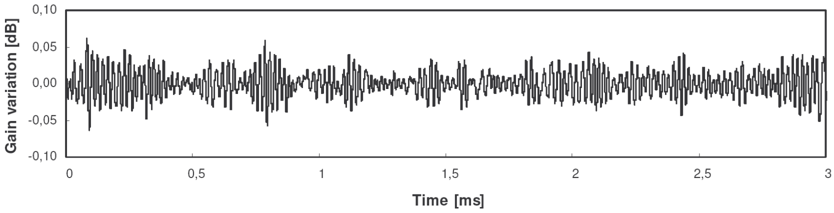

Figure 3. Gain variation for 16 burst channels and x=1.15.

Fig. 3 shows the gain variation induce by the trace of Fig. 2 for the OGC-OA working at $x = 1.15$. We do not see any appreciable variation (peak-to-peak gain 0.12 dB) as the OGC-OA in burst mode works with average power of -4 dB and no significant channel number change in times compared to laser dynamics inferior than 50 μs. This indicates that the OGC-OA will work well above the threshold and it is not subject to abrupt power variation as in an on/off case (15 out of 16 channels).

A different scenario is if the OGC-OA is used in few channel link with high channel power. A example we simulate a link with one channel link with -1dBm input. This case could also be interpreted as a simultaneous 16 channels on/off. Figure 4 illustrates the trace and the respective dynamics of gain variation [8]. As can be observed there is an interplay between burst sequence interarrival times and OGC-OA ROFs. In fact we have stronger gain variation than in Figure 3 as expected according to experimental verification in [4,7]. The real traffic data may therefore induce significant gain variation. In order to minimize the gain excursions and as consequence power transients in the channels, the OGC-EDFA should operate with a larger x value of about 1.5 or with shifted ROFs [7].

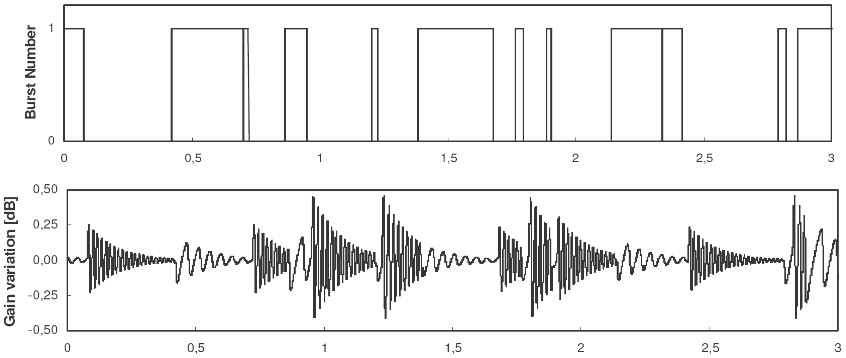

Figure 4. Burst trace and gain variation for input power of -1dBm and x=1.15.

4. EXPERIMENTAL RESULTS

Fig. 5 illustrates a schematic of the experimental set-up [9]. The lasing feedback wavelength is set to 1548 nm by means of a narrowband optical filter in the feedback loop. The amplifier gain is 17 dB for the input power of -3 dBm. The pump power is set to x = 1.3 to guarantee clamping robustness. The maximum total input power of 16 channels is -3 dBm while the CW-probe signal has -19 dBm at 1555 nm.

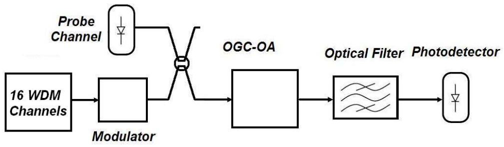

Figure 5. Schematic of experimental set-up.

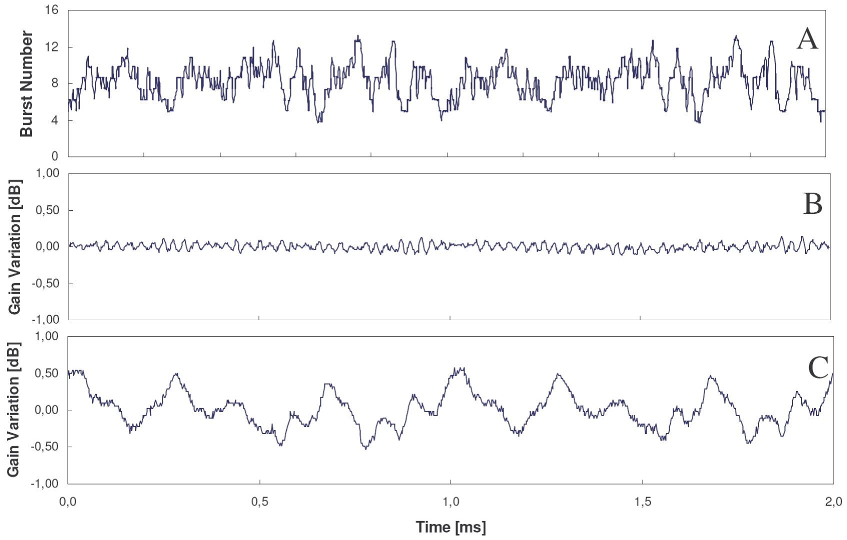

Figure 6. (A) Optical burst data at the amplifier input; (B) Gain variation with clamped amplifier; (C) non-clamped amplifier.

The behaviour of the OGC-OA is investigated for clamped and non-clamped amplifier to assess the dynamic performance [9]. Fig. 6A shows a sample of the WDM burst data trace used in the experiment to visualize the profile. Fig. 6B and Fig. 6C show the gain variations for the clamped and non-clamped amplifier, respectively. We notice that the peak-to-peak transients of the burst amplifier are four fold reduced compared to non-clamped case. In a typical network the signal will travel several amplifiers and the peak-to-peak penalty will accumulate and cause signal degradations. This demonstrates that the optical gain clamping technique reduces considerably the transients and could avoid extra penalties in the network. The random burst overlapping does not affect significantly the OGC-OA and an almost negligible interplay between ROFs and burst sequences is observed. A further improvement is expectable by reducing the laser cavity length using waveguide devices [11].

5. CONCLUSIONS

We have presented recent results on burst amplification. Theoretical and experimental investigations were carried out to assess the burst amplifier performance under real burst traffic. The optical gain clamping technique is shown to be simple, passive and efficient to avoid accumulated transients peaks in the optical burst switching networks. The results can be of further interest for long reach high splitting ratio WDM PON.

ACKNOWLEDGEMENTS

The work was carried out with the support of the BONE-project ("Building the Future Optical Network in Europe"), a Network of Excellence funded by the European Commission through the 7th ICT-Framework Programme and by the Welsh Assembly Government.

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