MEASUREMENT OF POWER SPREAD HISTOGRAMS IN CHAINS OF EDFAS FED BY MULTIMEDIA BURST-MODE PACKET TRAFFIC

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Abstract: We experimentally demonstrate the effectiveness of gain clamping in the reduction of output power spread in chains of EDFAs fed by burst-mode WDM packetized traffic with highly variable interarrival times and burst durations, typical of multimedia communications.

Introduction

In local, metropolitan, and wide area wavelength routing optical networks (WRON), there is a growing attention to the transmission of packet traffic directly onto the wavelength division multiplexed (WDM) channels. Such is the case for example of Internet Protocol (IP) packets over WDM, which avoids the costs of SONET/SDH equipment. While in SONET idle channels are treated at the physical level as scrambled non-empty bit sequences, so that the packet streams that feed the erbium-doped fiber amplifiers (EDFAs) in the network behave like continuous wave (CW) signals, in burst-mode packet transmission no optical power is transmitted during idle times, so that inter-packet idle periods of duration comparable to the EDFA response time cause sizable fluctuations of the EDFA average inversion and hence of its gain. Therefore the packet arrival and burst duration statistics play a key role in the EDFA gain dynamics, and hence in the dynamics of the output power on each WDM channel.

In [1] we showed that, in local WDM networks with a single EDFA, strong gain and output power fluctuations cause only mild optical signal-to-noise ratio (OSNR) fluctuations, so that the performance of optically-preamplified receivers is not much degraded by such dynamics, provided the received power remains within the dynamic range of the receiver. However, the performance of cheaper PIN or avalanche photodiode (APD) based receivers, which are dominated by electronic noise, is strongly degraded by such power fluctuations.

In larger networks with cascades of more than one EDFA, even the OSNR strongly degrades down the chain during gain transients [1], while power surges may cause strong transient nonlinear coupling in the fibers between the WDM channels [3]. In all such cases gain clamping [4] of some of the EDFAs may be a simple and effective solution to reduce the cross-gain modulation induced power excursions.

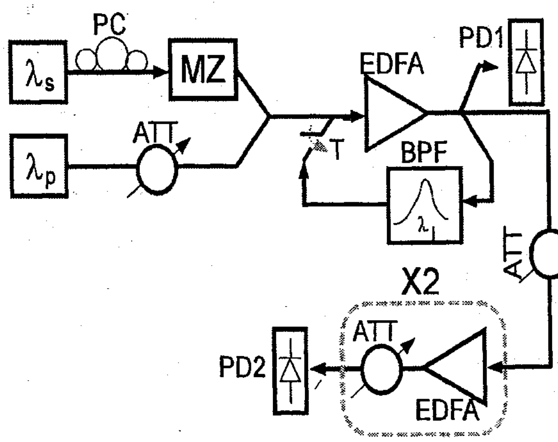
In this paper we measure the output power spread in a chain of both unstabilized and clamped EDFAs fed by highly variable burst-mode multimedia packet traffic [2], and quantify the effectiveness of gain clamping.

Measurements

The experimental set-up is shown in Fig. 1.

A CW signal at λ_s=1555.1 nm is ON/OFF modulated by an external Mach-Zehnder (MZ) modulator to emulate the presence/absence of packets. A polarization controller (PC) maximizes the power out of the MZ. A weak CW *probe* signal at wavelength λ_p=1553.5 nm is coupled with the modulated signal onto the fiber that feeds the chain. The peak powers at the EDFA input are P_s=-13.5 dBm for the

Figure 1 : Experimental set-up.



signal, and P_p=-20 dBm for the probe.

Such EDFA can be either in the unclamped (toggle T off) or clamped (T on) configuration, and its clamping laser oscillation, selected by a bandpass optical filter (BPF) at wavelength λ_l=1558.8 nm, is allowed to propagate to the downstream EDFAs. Either one or two unstabilized EDFAs follow, with interamplifier loss (regulated by variable attenuators ATT) of about 5 dBs. The power of the probe signal is measured at the output of the first EDFA on photodiode PD1, and at the end of the chain on photodiode PD2.

The burst-mode ON/OFF (packet) stream feeding the MZ modulator is generated off-line as an alternating renewal process according to the desired statistics of the ON and OFF burst times.

The ON times T_{on} are generated by the transformation: $T_{on}=\lfloor U^{-1/\alpha_{on}} \rfloor$, where $U \in [0,1]$ is a uniform random variable (RV), and $\lfloor x \rfloor$ is the floor function. This corresponds to a rounded Pareto RV, which has infinite variance when $1 \leq \alpha_{on} \leq 2$ [2]. OFF times are generated similarly with an α_{off} parameter. Such statistics well capture the high variability of multimedia traffic [5].

A random string of 16000 packet slots is synthesized off-line with the above method, and is programmed into the function generator that drives the MZ modulator. The string is repeated over and over. Each ON slot produces a rectangular pulse in the function generator, whose duration can be selected.

Figure 2 : Top graph: Probe signal voltage at PD1 measured with toggle T off(Unclamped) and on (Clamped). Bottom graph: MZ drive voltage.

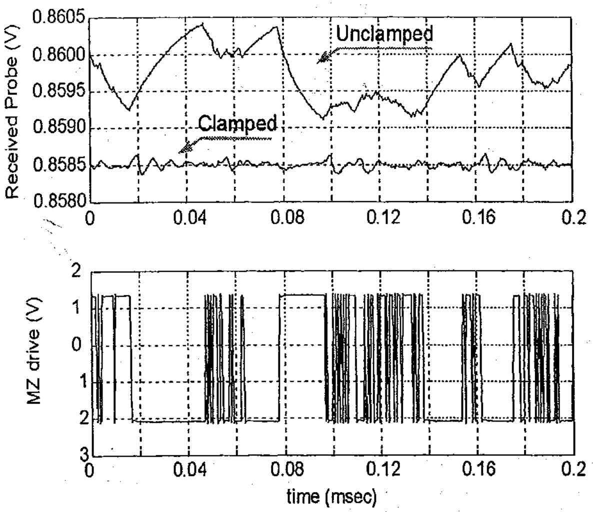


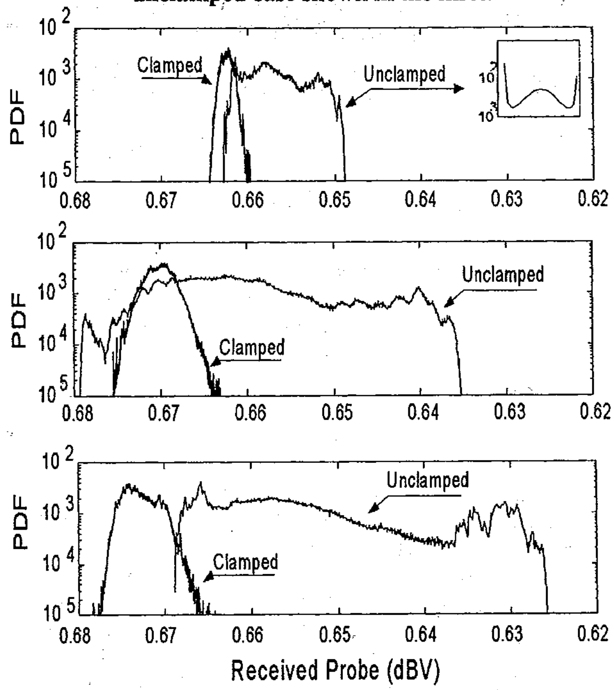
Fig. 2 shows the oscilloscope traces of a segment of the modulating sequence feeding the MZ (bottom graph), and the voltage at PD1 relative to the probe channel in both unclamped and clamped operation. The slot duration was set to 2.7 μs, corresponding to either asynchronous transfer mode (ATM) packets of 500 bits at 155 Mb/s, or IP segments of 4 kbytes at 10 Gb/s. The ON/OFF times were obtained with $\alpha_{on}=\alpha_{off}=1.2$, corresponding to infinite variance of ON/OFF times, and 50% channel loading. In the unclamped case the EDFA charge/discharge caused by long ON/OFF bursts is clearly visible. The probe power swings between an upper value corresponding to a long OFF burst in the modulated channel, to a lower value caused by a long ON burst. In the clamped case we observe a reduction of both the amplifier gain (i.e. of the average probe power) and of the gain fluctuations (smaller excursions with respect to the average value) in response to the same packet sequence. Long ON/OFF bursts cause the probe power to stay stable at its average value.

Fig. 3 shows the histogram estimates of the Probability Density Function (PDF) of the probe signal voltage measured at PD1 after the first EDFA, and at PD2 after either 2 or 3 EDFAs, when the *first* EDFA is either clamped (T on) or unclamped (T off). At the first EDFA, in the unclamped case, we observe a broad PDF, with a central mild peak and two edge peaks. The PDF is constrained in the range between a maximum (reached when the modulated signal is always OFF) and a minimum (modulated signal always ON). A more accurate PDF estimate, obtained by simulation using one million slots, is also shown in the inset. The central peak is placed roughly at the output probe power that would be obtained with CW input signals with power ρ dBs lower. The edge peaks (ideally Dirac delta functions) correspond to the finite probability that the probe power takes on the steady state maximum and minimum values. For smaller values of α (higher variability) such edge peaks become higher. For load values different from ρ=0.5 the PDF loses its symmetry.

In the clamped case the PDF has a bell shape. Clamping has the effect of reducing by more than 4 times (on a dB scale) the width of the PDF at 10^{-5}.

The PDF width increases down the chain, although when the chain saturates the PDF width tends to saturate as well. In the specific example, although in the unclamped chain the mean probe power increases, we observe a decrease in the clamped case, since with clamping the gain decreases

Figure 3 : Histogram estimates of the Probability Density Function (PDF) of the probe signal voltage, after: (Top) 1 EDFA; (center) 2 EDFAs; (bottom) 3 EDFAs. First EDFA is either Clamped or Unclamped. Simulated PDF at first EDFA in unclamped case shown in the inset.



to sustain the laser signal, and thus in our case the gain becomes lower than the interamplifier losses.

Although in our experiment the available powers at the chain input were small and thus the PDF spread was small, much larger power spreads can be forecast for larger input powers and larger channel numbers. If more than one modulated channel were present, assuming addition of the perturbations on the gain, one can infer that the resulting PDF is given by the convolution of PDFs with the above shape, which tends to a Gaussian distribution for many WDM channels by the central limit theorem [2].

Conclusions

We showed experimentally that stabilization of the first EDFA of a chain by gain clamping is a simple and effective technique that significantly reduces the power spread caused by gain fluctuations in burst-mode packet-switched WRONs. The effectiveness of clamping increases as the clamping laser oscillation increases in strength, which in turn implies a larger EDFA pump power for the same gain, or a lower gain for the same pump power.

References

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