LARGE POWER & SNR SWINGS IN CASCADED EDFAs CARRYING HIGHLY VARIABLE TRAFFIC

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Abstract: We show that cascades of EDFAs carrying packetized traffic with high variability can display large output power and SNR swings due to the gain saturation effect.

Introduction

Erbium doped fiber amplifiers (EDFA) employed in Wavelength Division Multiplexing (WDM) systems have been shown to incur system impairment due to transient gain saturation [/1/,/2/]. We examine the influence of the transient gain saturation on the output power and signal-to-noise ratio (SNR) swings in cascades of EDFAs carrying packetized traffic with high variability in interarrival times, and we demonstrate large output power and SNR swings due to this effect.

In WDM slotted packet-switching networks where no power is transmitted on empty slots, fluctuations of the input powers are present due to the random nature of the packet transmission giving rise to a cross-gain saturation effect. The impairment in packet networks, however, was not considered substantial due to the rapid fluctuations of the input powers relative to the EDFA fluorescence time. Network services such as multimedia, variable bit-rate (VBR) video, and gigabit Ethernet exhibit highly variable data. New studies have emerged indicating much increased variability in the packet interarrival times; measurements of traffic taken by Bellcore suggest evidence of self-similarity in these networks [/5/]. The significance of the increased variability or indeed self-similarity from the gain saturation perspective is that longer intervals of higher or lower input power are much more probable, giving enough time to the EDFA to acquire substantially different gain values. We investigate the system impairment in such WDM packet networks due to the gain saturation in cascades of EDFAs fed by input traffic with various degrees of variability in the packet interarrival times. Through numerical simulations, we demonstrate sizable power and optical SNR swings at the output of the EDFAs.

Simulations

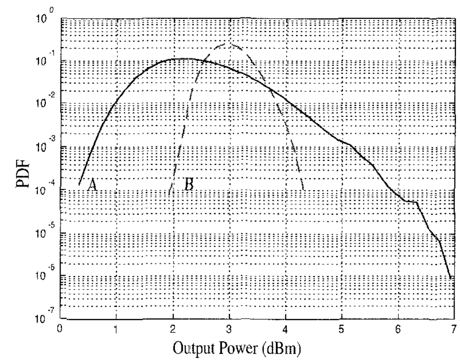
We simulate a cascade of five EDFAs, with a passband filter after every EDFA to block the amplified spontaneous emission (ASE) noise below 1540 nm and a notch filter after the fourth EDFA for gain equalization. The notch filter is assumed to have a Lorentzian shape [/3/] with filter depth 1.4 dB, center wavelength 1546 nm and filter width 2.5 nm. Each EDFA is assumed to have length of 14 m with forward pumping at 980 nm, the pump power being 18.4 dBm. All the spectral parameters of the EDFA were taken from [/6/], Table 4.2. A WDM system with 16 wavelength channels equally spaced between 1544 and 1559 nm was assumed with 1 nm spacing and with peak input power of -7 dBm. This guarantees (at network utilization of ρ=0.5) approximately 10 dB gain for all the channels to balance the interamplifier loss which was also assumed to be 10 dB. At the receiver, an optical filter was assumed with filter width 0.125 nm. The transient behavior was determined by solving numerically the differential equation as outlined in [/4/].

To test the effect of the statistics of packet interarrival times on the power swings, we simulated a 16-channel WDM system, each channel being an independent ON/OFF asynchronous transfer mode (ATM) source. Standard slotted ATM traffic was assumed with 53 bytes per cell and with bit rate 150 Mb/s. Fixed-size packets (or cells) have random arrival times, and each wavelength is time-slotted and synchronized at the EDFA output. It has been shown that the superposition of many ON/OFF sources whose ON or OFF periods have infinite variance can produce self-similar traffic [/5/]. The ON times T_{on} were generated as:

$$T_{on} = \left\lfloor \frac{1}{(1-u)^{1/\alpha_{on}}} \right\rfloor$$

where U is a random variable uniform on [0,1], $\lfloor x \rfloor$ indicates the floor function. This implements a (rounded) Pareto distribution, which has infinite variance when $1 \le \alpha_{on} \le 2$ [/5/]. The OFF periods were generated similarly with $\alpha_{on}=\alpha_{off}$, corresponding to a network utilization of ρ=0.5. The simulation was run for a million slots, corresponding to 3 sec of traffic at 150 Mb/s. The output powers and optical SNRs were arranged in a histogram form representing the estimated probability density function.

Fig. 1: Simulated probability density function of powers at the output of the first EDFA (curve B) and at the fifth EDFA (curve A) for $\alpha_{on}=\alpha_{off}=1.2$.



In Figure 1 we present the histogram of the power at the output of the first (curve B) and the fifth EDFA (curve A) for the channel at 1552 nm. While the power swings cover only 2.5 dBm for the case of a single EDFA, that range grows to nearly 7 dBm at the output of the fifth EDFA, a very substantial broadening. The power swings are larger further along the cascade due to the fact that the transients are much faster in a cascade [/2/].

Fig. 2: Simulated probability density function of powers at the output of the fifth EDFA: $\alpha_{on}=\alpha_{off}=1.2$ (curve A); $\alpha_{on}=\alpha_{off}=1.2$ and 2.5 Gb/s (curve B); $\alpha_{on}=\alpha_{off}=2.1$ (curve C); $\alpha_{on}=\alpha_{off}=5.0$ (curve D).

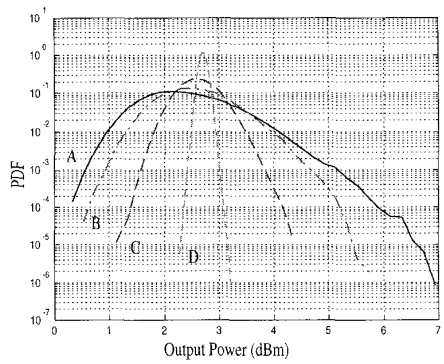
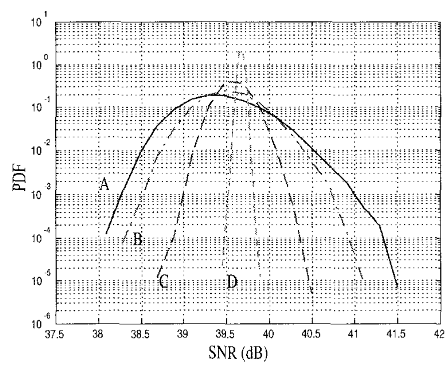


Figure 2 presents histograms of the power at the output of the fifth EDFA for various degrees of variability of the input traffic, ranging from self-similar traffic with α=1.2 (curve A) to the relatively "smooth" traffic with α=5.0 shown with curve D. Note that smoother traffic results in modest broadening of the power curve and curve D ($\alpha_{on}=\alpha_{off}$=5.0) features only 1dB broadening. As the traffic variability increases, the broadening increases as well, reaching almost 7 dBm for the self-similar case of $\alpha_{on}=\alpha_{off}$=1.2 depicted with curve A. Curve B features a system operating at a bit rate of 2.5 Gb/s with self-similar traffic as in curve A. Curve B exhibits less broadening than the system operating at 150 Mb/s (curve A).

Fig. 3: Same as Fig. 2, but for optical SNR.



Finally, Figure 3 shows the corresponding histograms for the optical SNRs. It can be shown that the maximum probability level of the SNR histogram in Figure 3 coincides with the steady state value of the SNR calculated for that particular utilization. Note that the broadening of the SNR curves is much less than that of the power curves. This is due to the fact that the transients of the SNR excursion are much slower as measured by the 1 dB times (the time during which the power transients reach the 1 dB level). That is, the 1 dB time of the power excursion at the output of the fifth EDFA stands at 7.4 µs, whereas the 1 dB time of the SNR excursion is 19.8 µs. Hence, the curves for the SNR cases are constricted, featuring a width of 3.5 dB for the self-similar case with ρ=0.5 and $\alpha_{on}=\alpha_{off}$=1.2 (curve A), as opposed to nearly 7 dBm for the corresponding power histogram. Again the broadening is more pronounced as the utilization decreases and the variability increases.

Conclusion

We have developed a simulation program capable of realistic analysis of the power and SNR transients in WDM optical networks employing cascades of EDFAs. In a rather extensive set of simulations, the simulation package was applied to investigate the influence of the statistics of the input traffic on the statistics of the output power and SNR levels. Modeling the input traffic as a succession of ON/OFF periods, each with Pareto heavy tail distribution, we have simulated input traffic with various degrees of variability in packet interarrival times. The result of the simulations were histogram representation of the estimated probability distribution function of the output power and optical SNR swings, taken for input traffic with different variability and for different network utilization factors. The results indicate that substantial power and SNR swings are present when EDFA is used to amplify high-variability traffic. The effect is much more pronounced in the case of cascades, where power swings in excess of 7 dBm and SNR swings of more than 3.5 dB were observed during the course of one simulation. This system impairment could lead to receiver dynamic range problems, and error bursts if the power exceeds certain thresholds for optical nonlinearities or inadequate eye opening. It should be stressed that the study determines qualitatively this effect in the case of highly-variable multimedia traffic and highlights the fact that cascades of EDFAs will make the problem of output power and SNR fluctuations more acute. Quantitative analysis of how large the impairment is depends very strongly on system parameters, as indicated by two parallel simulations for systems with significantly different EDFA parameters leading to significantly different values for the amount of broadening of the power swing curves.

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