Abstract We theoretically and experimentally demonstrate a new link control technique for EDFA based WDM ring networks with ASE light re-circulation which ensures, at the same time, limited transient effects, high network stability and survivability.

Introduction
Recent experimental studies have shown that the light, produced by lasing effect in EDFA based WDM ring networks with free amplified spontaneous emission (ASE) re-circulation, can provide an effective gain control mechanism [1],[2]. However, although ASE light re-circulation can ensure limited power transient under WDM channels add-drop operations, avoiding complex and costly devices and algorithms, two main limiting factors have been identified. The first one is related to optical signal to noise ratio (OSNR) degradation; in fact, in order to make the network stable under add-drop operations, relatively high span losses between consecutive EDFA are required. It is quite difficult to ensure good network stability and high OSNR at the same time. The second important limiting factor is that, in case of EDFA and fiber breakage, strong signal power excursions are expected because of loss of the clamping mechanism, provided by ASE re-circulation.

In this paper we propose to inject a laser beam at a given amplifier node of the ring network, and leave it free to circulate in the loop. We show that this laser beam, being centered around a wavelength where it is desired that a lasing peak is generated, provides great network robustness in terms of span loss variations, very limited power transients and improved OSNR performance. Moreover, this link control can also be exploited to guarantee high network survivability in case of fiber or EDFA breakage.

Experimental set-up and results
Fig. 1 shows the experimental set-up we have used to investigate the proposed link control technique. For the sake of simplicity, only four sections of 25 km standard SM fiber and four EDFA, operating at constant pump power (100 mW at 980 nm) were used. Three high power channels are multiplexed and switched on and off at 100 Hz, by an acousto-optic modulator, to simulate adding and dropping of 15/16 WDM channels, before being combined with a probe signal at 1554.9 nm. The probe dynamic behavior was observed after propagation along the entire looped network, with and without link control at 1532 nm, provided by a DFB laser which is also coupled into the network at the first EDFA input. Note that both link control and ASE light are free to circulate in the loop, while the three loading channels and probe signal are extracted at the last EDFA output by a fixed four channel add-drop multiplexer.

Figs. 2a and 2b show the output spectra with full network load and single probe channel at –20 dBm, respectively with and without link control. The network span budget (4x19 dB) is such that, without link control, gain peaking can form within the WDM signal band, depending on the actual network load. On the other hand, with link control, gain peaking is stable at 1532 nm. Note that the relative low loss of each span (19 dB) is advantageous in terms of OSNR performance (greater than 27 dB over 0.1 nm bandwidth) but is not at all optimal in terms of dynamic behavior and network stability. Fig. 3 compares the probe transient effects at the last EDFA output, with and without link control; larger power transients are present in the network only based on ASE light re-circulation, and higher span losses would be required in this case, in order to ensure steady operation conditions. Satisfying this condition would ensure stability of the ring. Note that after each loop transit time (~550 μs) the lasing light, re-circulating along the ring, clamps the gain with typical probe power transients induced by the lasing relaxation oscillations. The clamping mechanism, provided by
ASE light re-circulation, is only partially effective and the steady-state probe power level always remains above the steady-state condition with full network load; this is due to spectral hole burning and un-homogeneous gain. It can also be noted that the link at 1532 nm avoids formation of a double ASE peak at around 1532 nm, providing higher robustness to polarization dependent effects.

Network survivability
The use of link control techniques also allows one to perform, with limited additional cost, a node amplifier structure ensuring network survivability. Basically, each amplifier node can be equipped with a DFB laser which can be activated in case of network failure, caused by fiber or EDFA break. A network failure can be easily detected in each node by splitting a small fraction of the total power at the EDFA input, and recognizing the presence of lasing light within the loop. If the lasing light falls below a given threshold, the DFB laser is switched on.

We have investigated this network scenario using an experimentally validated dynamic model [3], which describes ASE light re-circulation and link control in EDFA based WDM ring networks. Fig. 4 compares the probe transient effects, respectively with and without network survivability scheme, at the last amplifier output of a ring network, composed of eight sections of 25 km SM fibers and eight EDFA. The network works in normal operation condition with ASE light re-circulation, without link control. Following a fiber break, supposed to be instantaneous (worst case scenario), the first amplifier node after the EDFA break will activate the corresponding DFB laser at –10 dBm, with a delay of 5 µsec, caused by the electronic circuit implementing the threshold detector. It is clear from Fig. 4 that the proposed scheme effectively prevents large signal power excursions ensuring network survivability.

In conclusions, we have theoretically and experimentally proposed and demonstrated a new link control technique for EDFA based WDM ring networks with ASE light re-circulation, which ensures limited power transients, high network stability and survivability.

Acknowledgments: We thank Mr. P. Ghiggino for helpful discussions and suggestions.

References
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