Field Trial and Lab Demonstration of Fast SRS Suppression in a C+L Band Optical Network

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Abstract: We report a first ever successful demonstration of a C+L band network, where following an induced L-band failure, we perform a fast recovery of surviving C-band channels and prevention of traffic hits.

1. Introduction

The need to upgrade optical networks to higher capacity is being driven by ongoing advances in Internet services and applications such as cloud computing, high-definition video, big data analysis, and so on. This challenges operators to seek efficient and timely solutions to meet the fast increase in bandwidth demanded by customers. Operators need a high-capacity solution immediately to address growing service demands with limited fiber resources. An efficient scheme for increasing the network capacity is using both the C and L bands on the same fiber. C+L band operation indeed increases network capacity two-fold, but it has its own challenges.

In particular, the strong stimulated Raman scattering (SRS) between the C and L bands leads to power transfer from the C-band channels to the L-band channels and results in effective extra loss for the C-band channels. This extra loss, although compensated by the
plifiers, degrades the performance of the C-band channels versus a pure C-band network.

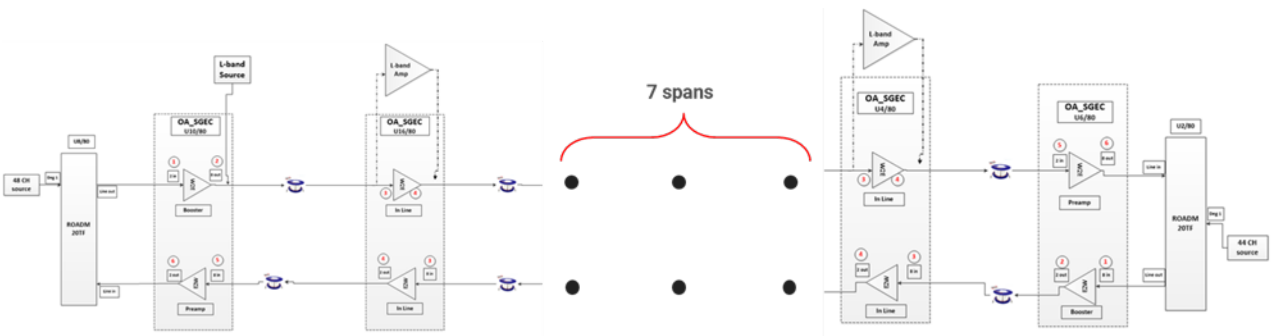

Fig. 1. A schematic presentation of the field-trial

The strong SRS interaction between the C-band and the L-band channels may also lead to another phenomena which is unique to C+L band networks. A sudden failure in one of the bands has a strong and immediate impact on the performance of the other band. For example, in the case of an L-band failure, due to an equipment failure or a fiber cut, the C-band loss in each fiber span is instantly reduced. This induces a significant power increase of the C-band channels that may cause a traffic hit. Traditional gain control methods to restore the channels' power usually takes place within few seconds and are too slow to cope with the expected traffic hit.

In this paper, we demonstrate for the first time (to our knowledge) a C+L Network where the traffic hit to the surviving C-band channels due to an L-band failure has been reduced to a few tens of milliseconds, by using a local fast gain correction during the failure.

2. Modeling of SRS interaction

The SRS interaction between the C and L bands is well known. In particular, the evolution of any channel power as it propagates along the fiber due to fiber loss and SRS interaction may be described by the following equation:

$$\frac{dP_i}{dz} = -\alpha_i P_i - \sum_{j=i+1}^{N} g_{i,j} P_i P_j + \sum_{k=1,i>1}^{i-1} g_{k,i} P_i P_k \tag{1}$$

where, P_i and α_i are optical power and fiber attenuation of 'i-th' channel, $g_{i,j}$ is Raman gain coefficient between 'i-th' and 'j-th' channels, and N is total number of channels in C+L band. The 1st, 2nd, and 3rd terms in eq.(1) represent, WDL, loss and gain due to SRS from blue to red channels and vice-versa, respectively.

We employ eq.(1) to simulate the SRS interaction between the C and L-bands, for many cases of different channel power, different channel distribution, different fiber types and attenuation. Then, we were able to find a general first-order approximation for the generated C-Band loss and C-Band Tilt due to the SRS interaction with the L-Band:

$$\begin{aligned} \text{SRS-tilt}_{\text{C/L-band}} = & \xi \times \kappa \times \frac{0.22}{\alpha} \\ & \times (P_C + P_L) \times \frac{1}{100} \end{aligned} \tag{2}$$

where, P_C and P_L are total power (mW) in C- and L-bands, $\xi = 0.9$, κ depend upon fiber-types ($= 1, 1.12, 1.45$, and 1.54 for G.652.D, G.655.A-D (LEAF), G.655.C,D (Truewave RS), and G.656 (Truewave REACH), respectively), and α is fiber attenuation. All the coefficients (ξ, κ, and α) are idenependent of optical power and channel population and distribution. Further, SRS-loss$_{\text{C-band}}$ and SRS-loss$_{\text{L-band}}$ in dB scale can be expressed as,

$$\begin{aligned} \text{SRS-loss}_{\text{C/L-band}} = & \pm \chi_{C/L} \times \kappa \times \vartheta_{C/L} \times U_{C/L} \\ & \times \frac{0.22}{\alpha} \times (P_C + P_L) \times \frac{\eta_{C/L}}{100} \end{aligned} \tag{3}$$

where, $\eta_{C/L} = \sqrt{\frac{P_{L/C}}{P_C+P_L}}$, P_C and P_L are total power (mW) in C- and L-bands, $\chi_{C/L} = 0.8$ and 0.6 for C- and L-band, respectively. $\vartheta_{C/L}$ and $U_{C/L}$ dpends upon channel population and distribution, respectively and define as, $\vartheta_{C/L} = \min\left[1, 1.25 \times \left(\frac{N_L}{N_C}\right)^{\pm\frac{1}{3}}\right]$, $U_{C/L} = 1 - \delta \times (R_C + R_L - 2) \pm 0.5 \times (R_C - R_L)$, where $\delta = \min\left[1, \left(\frac{N_L}{N_C}\right)^{\pm 1}\right]$, '$+$' and '$-$' signs are for C- and L-band, respectively. N_C and N_L are channel populations in C- and L-band, respectively. R_C and R_L repersents the index of uniformity in distribution of channels in C-and L-band, respectively and defined as,

$$R_{C/L} = 1 + \frac{\sum_j \left[f_j - f_{C/L,\text{mid}}\right] \times \text{BW}_j}{4.75 \times \text{BW}_j} \tag{4}$$

where, f_j is frequency in THz, and BW_j in GHz of 'j'-th channels, $f_{C/L,\text{mid}}$ is frequency (in THz) of middle channel of C/L-band. $R_{C/L} =, >, < 1$ for uniformly distributed, more blue than red, and more red than blue channels, respectively.

Note that the SRSloss is defined as the extra loss of the C-band middle channel (193.735THz) due to the SRS interaction with the L-band channels. The SRSTilt is defined as the extra C-Band Tilt due to the SRS interaction. Similar equations may be derived for the SRSGain and SRSTilt of the L-band.

We use eq.(2)-(3) to estimate the change in the SRS-tilt and SRS-loss, in case of a band failure. Each amplifier constantly monitors the input and output power of both bands. Based on the monitored power and eq.(2)-(3) the instantaneous SRS-tilt and SRS-loss are calculated. In the case of a band failure, or in general, when the power of either or both bands is changed such that the SRS-tilt and SRS-loss are modified by more than a pre-determined threshold, the amplifier immediately modifies its gain and/or tilt to compensate for the change in the fiber tilt and/or loss.

3. Field Trial and Lab Demonstration

As a first step, C+L transmission was successfully trialed over Airtel's network in India. Fig. 1 depicts the optical network transmission link, which is made of ten spans of standard single-mode fiber (SSMF, G.652). Each span's length is between 60 to 90km and the loss is between 18 to 24dB. Each of the ILAN (in-line amplifier) sites includes a C-band high-power gain-switched EDFA that may be easily upgraded to also support L-band transmission by adding a similar L-band EDFA. The EDFAs are mid-stage access EDFAs that include a DGE (Dynamic

Gain Equalizer) to enable perfect equalization of the propagating channels. This overcomes the dynamic nature of the "L-band ready" network where channels may be added and dropped over the life of the network.

Employing a combination of Flex-Grid and Hybrid-modulation techniques, we transmitted channels over the field trial network at various line-rates, bandwidths and symbol rates, as summarized in Table 1.

Table 1. The various channels transmitted over the Field-Trial Network

Line-rate, Gb/s	BW, GHz	Symbol-rate, G-Baud	Total Capacity, Tb/s	Q-margin, dB
300	62.5	46.3	46.08	5.1
300	75	61.2	38.40	6
350	75	60.7	44.8	5.1
400	75	63.0	51.2	2.8
400	87.5	69.4	43.89	4

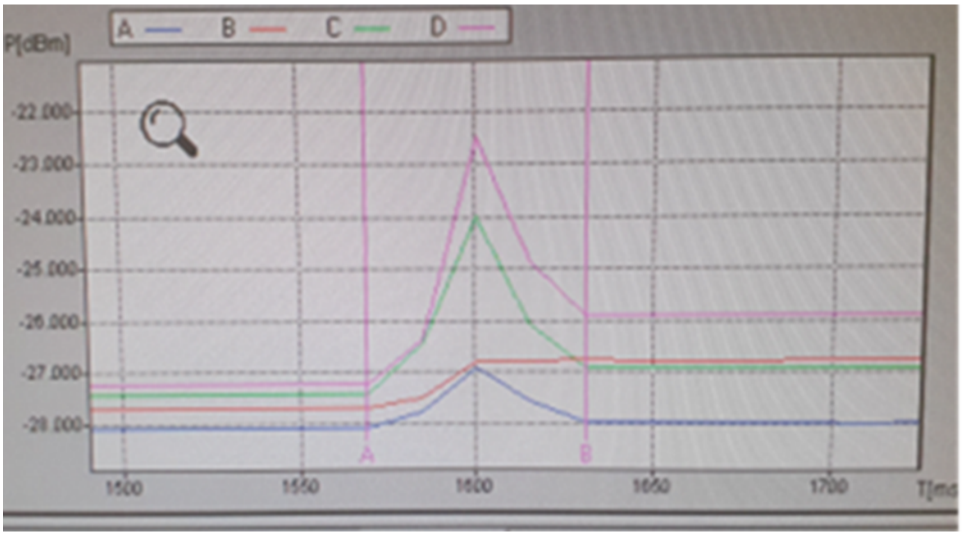

Fig. 2. SRS-Loss$_{C/L\text{-band}}$ vs N_L for (a) uniformly and (b) randomly distributed channel populations in C+L bands.

As a second step, we reconstructed the field trial network in a lab environment to test its vulnerability to, and demonstrate its recovery from, a band-failure. Notably, the network reaction to a band failure was tested with full L-band capacity and half-full C-band capacity (to avoid saturation during the test). For such conditions, and according to Eq.2a, the expected SRSloss is between 0.6 to 1.4dB per span. (The injected power to each span depends on the span loss in order to optimize the network GOSNR). The L-band failure was simulated by mimicking a fiber cut by a fast optical switch that leads to L-band removal within few milliseconds.

Fig. 2 shows the power of a C-band channel (191.7THz) during an L-band failure event. Fig.2a, presented over milliseconds scale, is a zoom-in into the immediate behavior of the channel following the L-band failure. The L-band failure stops the SRS power transfer from the C-band, which leads to a reduction of the effective span loss and results in power increase of about 5dB at the output of the last EDFA. However, as explained in section II, the system immediately acts by reducing the EDFA's gain in the amount calculated by Eq.2a. Thus in less than 30msec the channel power is recovered and stabilized at a level that is about 1.2dB higher than its target power.

Note that the approximations employed to derive Eqs.2 do not lead to perfect restoration of the channel power. The SRS recovery process only acts as a "first-aid" that keeps the channel's power within the network tolerance, thus avoiding a traffic hit. A few seconds after the L-band failure, the slower network power control process (few seconds scale) adjusts each EDFA Gain according to the actual span loss and leads to a perfect recovery of the channel power. Both processes, the fast SRS recovery and the slow power control are presented in Fig.2b.

4. Conclusion

An 800km C+L bands, flex-grid, hybrid-modulation transmission, was trialed over Airtel's network in India. This network was then replicated in a lab environment where a unique fast SRS suppression technique was successfully demonstrated that prevents a traffic hit to the surviving channels following a band failure.

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