Deployment results of super C(120)+L(100) long-haul optical transmission system with fast distributed fault recovery

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Abstract: We discuss the hardware, architect and system control of a C+L long-haul transmission link with 11THz total bandwidth. We show that a hierarchy fast distributed fault recovery mechanism is critical for the successful system deployment. © 2023 The Author(s)

1. Introduction

Baidu's backbone optical network provides low-latency and highly-reliable capacity that underpins Baidu AI Cloud's secure services platform to offer a rich product portfolio for customers to build sophisticated applications with flexibility, scalability, and reliability. Over the last five years Baidu's long-haul optical network's capacity has scaled by approximately seven times. As the number of mutually exclusive fiber routes between two data centers is very limited, while deploying new fibers on the same route could increase the fault domain due to frequent fiber interruptions, pushing per-fiber capacity becomes the most promising approach to meet the capacity demand.

Governed by Shannon capacity, enhance single-channel spectral efficiency and expand available bandwidth are the two key strategies to increase the single-mode-fiber capacity. The state-of-art optical transponder equipped with probabilistic constellation shaping [1] is already approaching the Shannon limit, therefore keep pushing the transceiver SNR performance does not generate meaningful benefit. Instead, adding another 5THz low-loss L-band wavelength window in addition to our existing C-120 (super C) system leads to largest return due to its linear capacity gain nature while fully exploits the existing fiber infrastructure. In this paper we would discuss the hardware of a L-100 EDFA that supports the longest wavelength at 1617nm; ASE-based solution for a smooth C+L system upgrade; and by embedding span loss compensation, ASE automatic injection and Stimulus Raman Scattering (SRS) control, a hierarchy distributed fault recovery scheme can be built that allows fast self-healing from major system faults such as fiber cut, fiber loss degradation and hardware failure.

2. Network architect, ASE-based L-band upgrade and L-band EDFA

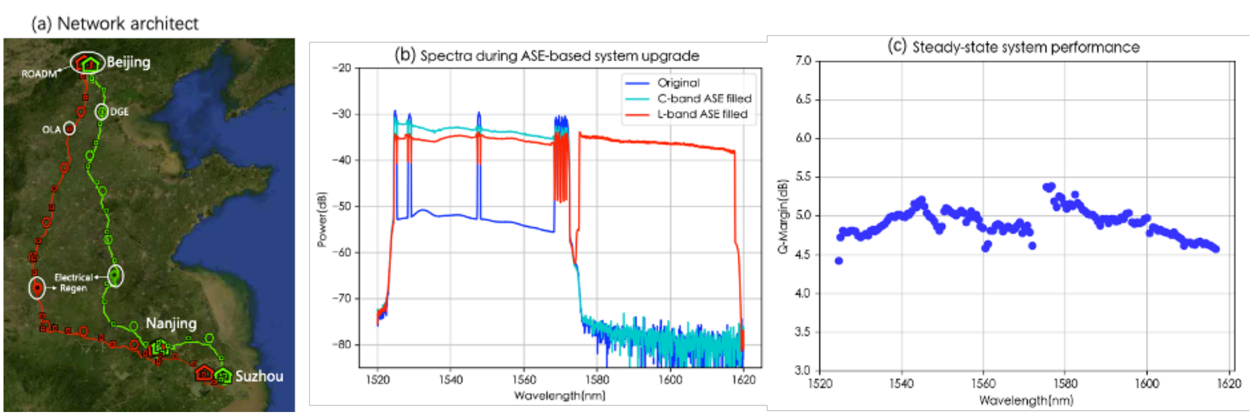

Fig. 1 (a) System architect of the deployed network; (b) spectra during L-band upgrade; (c) steady state Q-margin of all channels.

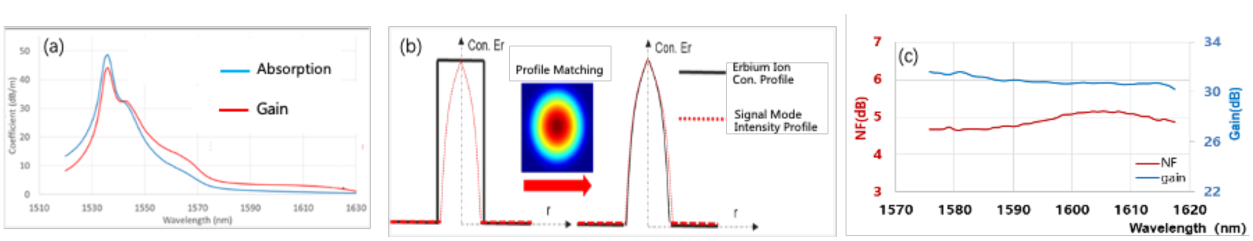

Fig. 2 L-100 EDFA: (a) Absorption and gain coefficients; (b) Erbium ion and signal mode intensity profile; (c) NF and gain.

Fig.1(a) shows the system architect of the deployed network, six Baidu super core data centers in three regions were interconnected to form a six-point ring network, with more than 3500km total fiber length. The line system consists of ROADM sites (i.e. data centers), OLA sites, DGE sites and electrical regenerator sites. DGE site was placed after every two OLA sites, and the electrical regenerator sites were built at the middle of each link, optical channel protection (OCHP) was used for all wavelengths.

There are three steps for the L-band system upgrade: C-band ASE filled, L-band ASE filled and traffic scaling. Fig.1(b) shows the receiver spectra during the addition of L-band system. Initially there were only eight C-band channels on the system, after installation of all the L-band hardware and completing the physical fiber connection (the C/L Mux/DeMUX is integrated with the C-band amplifier), C-band ASE source was turned on to fill the rest of the C-band spectrum, and the entire link configuration was fine tuned to optimize the entire C-band performance; and then the L-band spectrum was loaded with ASE, and the C+L-band line system was co-optimized, obviously the received C-band power was reduced due to the appearance of the L-band signal. The traffic scaling was achieved by per-channel signal-ASE replacement, where the WSS adjusted the attenuation on the corresponding channel to realize an identical integrated power before and after the process, also doing one channel at a time created minimal power disturbance to all other wavelengths and do not require any dynamic re-configuration. Both C-band and L-band wavelengths use 64GBaud dual-polarization QPSK at 200Gb/s line rate with 75GHz grid spacing. All channels' steady-state performance is depicted in Fig.1(c), with an average Q-margin of 5dB.

For the L-100 EDFA, enhanced doping composition and concentration are used to combat the well-known excited state absorption (ESA) effect [2], which becomes significant for wavelengths above 1590nm. Also the pump conversion efficiency is improved by matching the erbium ion and signal mode intensity profiles as shown in Fig.2(b). The L-100 EDFA could achieve similar NF performance as C-120 EDFA with above 31dB maximum gain.

3. Hierarchy distributed fault recovery

The key challenge of field deployment of the super C+L system is to build a reliable fault recovery control mechanism that covers the major system fault cases such as fiber cut, fiber loss degradation and hardware failure, as adding the L-band leads to approximately 4 times SRS effect compare to the conventional C-band only system. The fault recovery system was portioned into four aspects: wavelength planning, OSC based span loss compensation, ASE automatic injection and SRS compensation.

3.1 Wavelength planning

The aim of wavelength planning is to minimize the SRS change when pass-through wavelengths are dropped due to fiber cut. For instance, in our scenario where ROADM A and B are in the same region, and ROADM C and D are in the other region, the traffic flows from ROADM A <-> C and ROADM B<->D, with backup routes of ROADM A<->B<->D<->C and ROADM B<->A<->C<->D, respectively. Therefore, when the fiber linking ROADM A<->B (or C<->D) is cut, both main routes lost its backup paths as well as the pass through channels, creating massive SRS change to the remaining channels that could lead to service interruption. We select to odd/even interleave the channels on two main routes such that when ROADM A<->B is cut, half C-band channels and L-band channels are lost at the same time, that balances and minimizes the SRS changes at both sides.

3.2 Span loss compensation

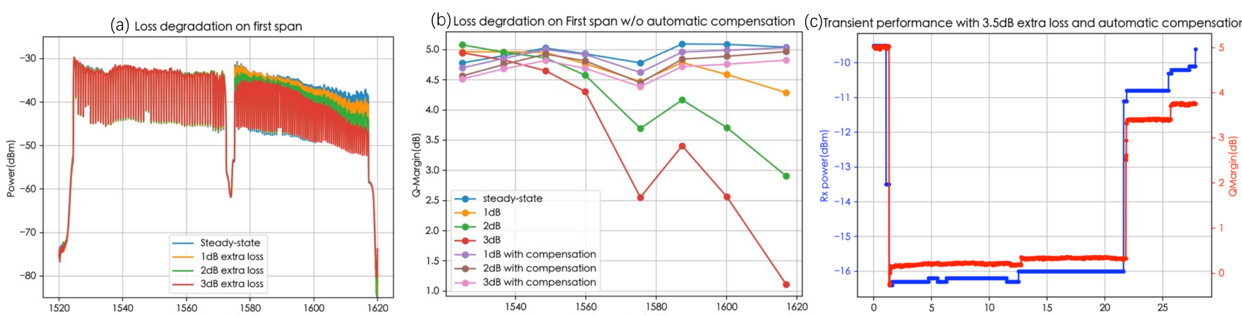

Fig. 3. Span loss degradation on first span: (a) Spectra, (b) Q-margin w/o compensation, (c) transient performance at longest L-band wavelength

Span loss degradation is another key factor that causes wavelength performance imbalance. Fig.3(a) shows the received spectra when there is 1/2/3dB span loss degradation on the first span. As shown in Fig.3(b), the longest L-band wavelength showed ~4dB Q-margin loss compare to steady-state when there is a 3dB extra loss on the first span. This is because the span loss degradation causes extra SRS loss to the L-band, and it linearly increases with wavelength. Optical supervisory channel (OSC) based span loss degradation detection and compensation is adopted to reverse the degradation and to maintain the system margin especially for the L-band long wavelengths. The transient performance (10ms per data point) of the longest L-band wavelength is shown in Fig.3(c), where the entire monitoring and compensation process takes ~20seconds, this is because we have set relatively long hold-off time before the actual gain adjustment in order to avoid fiber jittering case that is very common in our network.

3.3 ASE automatic injection

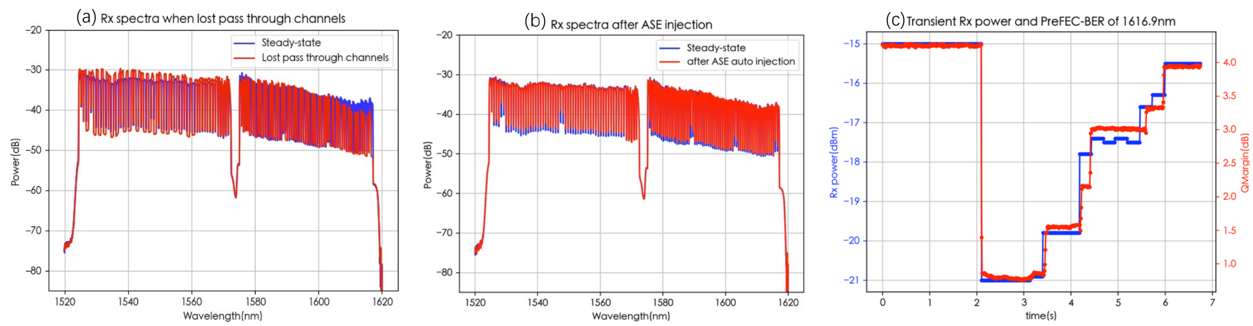

Fig. 4 ASE automatic injection: (a) spectra when loss half channels, (b) spectra after ASE injection, (c) transient performance at 1616.9nm.

ASE automatic injection is adopted to fill the full spectrum when there is a channel lost. We split the root cause into pass through channel loss (e.g. due to inter-site fiber cut) and local channel loss (e.g. due to hardware or in-site fiber failure), so we only use OCM to monitor the local add ports status to detect local channel loss, and use LOS on all other ports to sense pass through channel lost. The ASE injection process takes about 4 seconds as shown in Fig.4(c), as we gradually release the ASE power during the process due to cascaded amplifier transient effect consideration.

3.4 SRS compensation

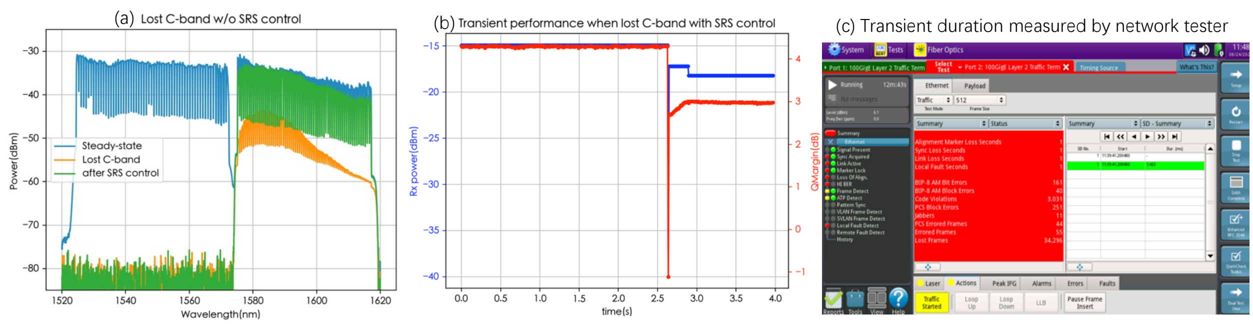

Fig. 5 (a) Spectra when lost C-band, (b) transient performance with SRS control, (c) network tester showing less than 2ms service disruption

We have implemented an ultra-fast SRS control scheme, all OLA and DGE sites continuously sense the total input/output power of both-bands to determine if it would impact the SRS transfer on the next span, otherwise immediate gain adjustment will be taken. Fig.5 shows an extreme example, where the entire C-band is lost (e.g., due to C-band OA/WSS failure) that causes largest SRS change, the fault domain doubles as the remaining L-band wavelengths are all under FEC threshold. The SRS control scheme equivalents the C-band lost to a next-span ~1dB L-band SRS loss, so all L-band amplifiers would enhance its gain simultaneously that could bring the L-band signals back to business. This scheme is implemented in a distributed manner where no inter-site communication is needed, and it only relies on total power detection that could achieve a sub-2ms end-to-end completion time as in Fig.5(c).

4. Conclusions

We have presented the deployment results of expanding a C-120 system with 5THz L-100 wavelength window. ASE source is deployed for both steady-state L-band system upgrade and fault-state automatic injection. Wavelengths are carefully assigned for each network degree to minimize the SRS effect, span loss and SRS compensation are jointly applied to cope with fault scenarios from all-wavelength and per-band perspective.

5. References

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