Field Deployment of Advanced Photonic Technologies for Ultra-High Bit Rate and Ultra-Long Reach Terrestrial WDM Transmission in Brazil

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Abstract: 100G deployments in the Amazon rainforest and over aged fiber plants are reported. Raman amplification enabled both bridging very long spans and minimizing the amount of nonlinearities in the line fiber.

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1. Introduction

The insatiable quest for higher capacity in the optical backbone networks, fueled by video, cloud and other high-capacity services, applies to both mature and emerging countries worldwide and in any geographical areas as well. Installation of new, high data rate backbone networks continues apace as a key driver for economic advancement in developing regions of the world. Providing a reliable telecom infrastructure is as vital for the economic development of a country or remote communities as road network is for transporting physical goods, or water or power distribution networks for the health of the population. Lack of access to long-distance connectivity and high-speed information prevents small communities from staying current with progress and advancing globalization.

Using the standard PM-QPSK modulation format for 100G channels in practical carrier backbone networks [1], recent works shown the value of Raman amplification technology for achieving high capacities over long all-optical path and bridging long spans between sites [2-4].

This paper reports the deployment of advanced photonic technologies (namely 100G channel rate, soft-decision FEC and distributed Raman optical amplification) in TIM Brasil backbone networks in two parts of Brazil (Figure 1), over different types of line fiber (including ITU-T G.653 fiber) and long spans between intermediate sites (up to 278 km).

Fig. 1. TIM Brasil network reported in this paper.

2. Key Technologies for Terrestrial Backbone Networks

Distributed Raman amplification (with optical pump sources located at the terminal and intermediate sites) is crucial in ultra-high bit rate and ultra-long reach terrestrial WDM backbone networks, since it provides gain in the line fiber itself, improves the Noise Figure (NF) of the spans and mitigate fiber nonlinearities. Raman amplification can be applied at the beginning of the span (co-propagation with the signals) or at the end of the span (counter-propagation) on a per span basis depending on the actual attenuation to be compensated for. For short spans (typically with attenuation lower than 25 dB) in 100G networks, no distributed Raman amplification is used. For very long spans (typically with attenuation higher than 35 dB), both forward and backward distributed Raman amplifications are applied. The pump lasers in Raman modules are polarization-balanced for low polarization dependent gain and wavelength multiplexed into the line fiber using a standard high power connector (Diamond E2000PS). Production backward Raman pump modules consist of 5 pump wavelengths in the 1420 to 1500 nm and can deliver up to 1.9 W of distributed pump power. Production forward pump modules include 3 pump wavelengths (1430 ~ 1480 nm) and can delivers up to 0.85 W. The typical Relative Intensity Noise (RIN) of the pump laser diodes is -105 dB/Hz.

100G interface cards are based on the conventional coherent PM-QPSK format and are modulated at 120 Gbit/s gross rate which accounts for the 15% overhead of the Soft-Decision Forward Error Correction (SD-FEC). SD-FEC can correct a Bit Error Ratio (BER) of 1.9×10^{-2} to less than 10^{-15}. The received signals are processed by Digital Signal Processing (DSP) embedded in the coherent Application-Specific Integrated Circuit (ASIC).

3. 100G Optical Backbone Network on OPGW Cables in the Amazon Region

TIM Brasil 2,266 km long-distance optical transmission infrastructure in the Amazon region includes, in addition to terrestrials spans buried in the ground, 1,835 km of aerial Optical Ground Wire (OPGW) cable deployed along an aerial power grid, running between the tops of 3600 high-voltage electricity pylons and connecting the cities of Manaus, Macapa and Gopa as depicted in Figure 2.

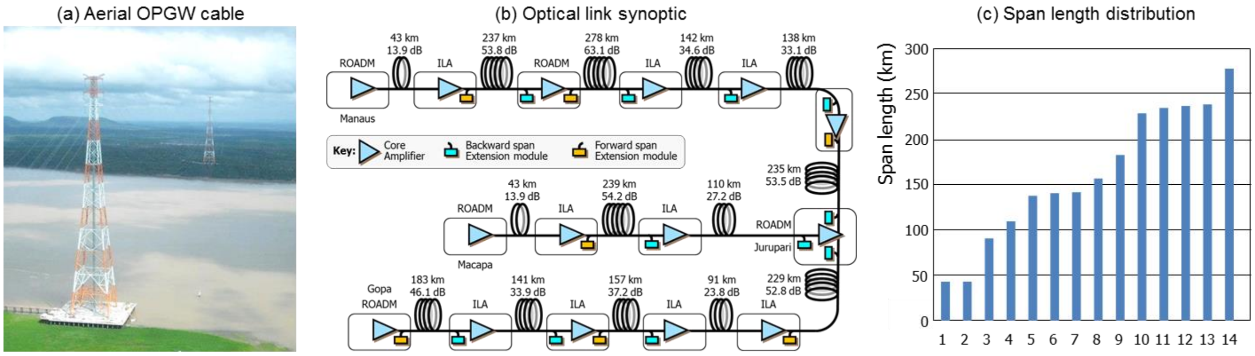

Fig. 2. Aerial OPGW cable crossing 2.5 km span across the Amazon River (a), synoptic of the 2,266 km backbone network in the Amazon region (b), and span length distribution (c).

Figure 2(a) shows 295 m tall transmission towers erected for crossing 2.5 km wide Amazon River. Figure 2(b) provides the synoptic of the 2,266 km ITU-T G.652 Amazon backbone network with spans lengths and attenuations. Raman forward and backward pumping modules are represented by rectangular boxes and highlighted in orange and blue colors, respectively. Figure 2(c) represents the span length distribution across the 14 spans, with 11 spans exceeding 100 km, and 5 out of 14 spans exceeding 200 km. The longest span is 278 km long with attenuation at end of life of about 63 dB (including margin for repair of 3 dB).

The three-degree node located in Jurupari is built with a colorless, directionless ROADM node. This ROADM site is used to add/drop local traffic and to carry out off-line regeneration for long optical paths, e.g. Gopa to Manaus. The other ROADM sites are used only for local add/drop traffic. The Jurupari - Manaus TIM link is made of six spans with attenuation ranging from 13.9 to 63.1 dB. Three out of the six spans exceed the length of 200 km (235, 237 and 278 km) as shown in Figure 3.

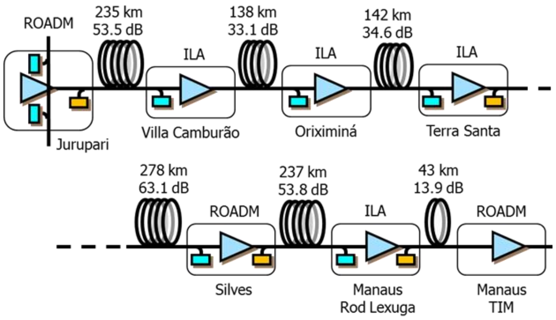

Fig. 3. Jurupari - Manaus TIM link synoptic.

Figure 4(a) shows the simulated evolution of the OSNR at each of the site along the Jurupari - Manaus TIM link. Starting from 33.2 dB at the input of the first span, the OSNR is 13.8 dB at the receiver input at the end of the last span in Manaus TIM site.

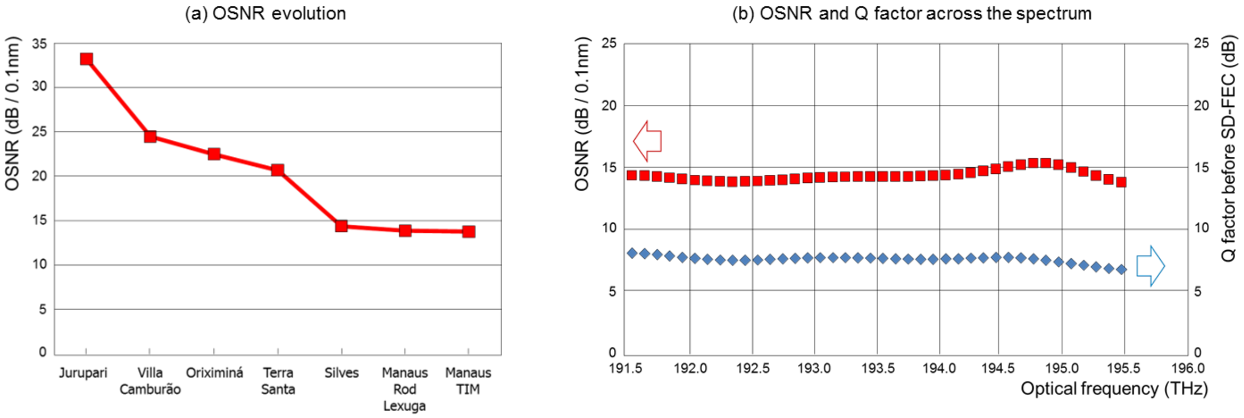

Fig. 4. OSNR evolution along the Jurupari - Manaus TIM link (a), and simulated OSNR (red squares) and Q factor (blue diamonds) performances across the spectrum at the link output (b).

Figure 4(b) shows the simulated OSNR figures and Q factor performance after the SD-FEC across the spectrum at the output end of the Jurupari - Manaus TIM link for forty wavelength-multiplexed and transmitted 100G channels spaced 100 GHz apart. The mean OSNR is 14.4 dB with the lowest value (13.8 dB) being observed for the channel located at 195.5 THz (or 1533.47 nm). The mean Q factor before FEC processing is 7.5 dB with the lowest performance (6.7 dB) being achieved by the same channel. The long-term BER measurements of the first 100G channel put in service ranged from 1.4 to 1.8 x 10^{-5} corresponding to pre-FEC Q factor of 12.3 to 12.4 dB. This figure provides a 6 dB Q margin to take into account margin for future cable repairs and full channel load.

4. 100G Transmission over an ITU-T G.653 DSF Link

100G coherent and Raman amplification technologies were also applied to another part of TIM Brasil network in order to increase the capacity of an aged 1,161 km terrestrial fiber route based on ITU-T G.653 fiber (Dispersion Shifted Fiber) between Fortaleza and Salvador. Fortaleza is the landing point for several high-capacity submarine cables connecting Brazil with North America and Europe so increasing the capacity of this old ITU-T G.653 route was of the upmost importance to TIM Brasil. Figure 5(a) describes the link with a short section of G.652 fiber at each end of the route in Fortaleza and Salvador metro areas (10 and 15 km, respectively). In both of these metro areas, these G.652 fiber sections support both 10G channels for local traffic and long-haul 100G channels.

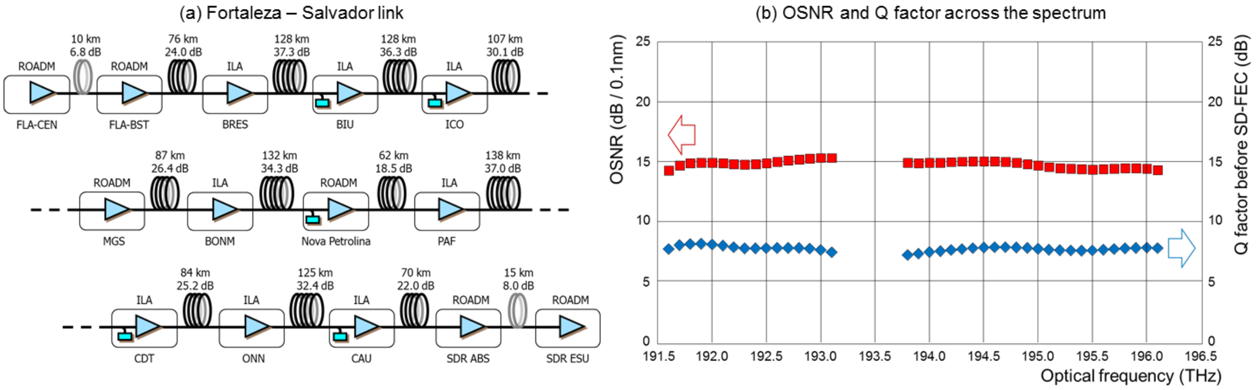

Fig. 5. Fortaleza – Salvador ITU-T G.653 link synoptic (a), and simulated OSNR (red squares) and Q factor (blue diamonds) performances across the spectrum at Fortaleza - Nova Petrolina link output (b).

Figure 5(b) represents the simulated OSNR figures and Q factor performance after the SD-FEC across the spectrum at the output end of the Fortaleza - Nova Petrolina 668 km link for 40 x 100G channels. In order to avoid the too low chromatic dispersion region, no channels were located 193.2-193.7 THz (1547.72 and 1551.72 nm). Also the launched powers and amount of distributed Raman gain inside the G.653 line fiber were adjusted to minimize Four-Wave Mixing (FWM) nonlinearities. The mean OSNR is 14.7 dB with the lowest value (13.8 dB) being observed for the channel located at 191.6 THz (or 1564.68 nm). The mean pre-FEC Q factor is 7.8 dB with the lowest performance (7.2 dB) being achieved by the channel located at 193.8 THz (or 1546.92 nm).

5. Conclusion

100G and Raman amplification technologies are today mature enough for deployments in hostile environments (e.g. in the Amazon rainforest) and over aged fiber plants that were not originally designed for WDM operation (e.g. ITU-T G.653 fiber). In the practical deployments reported in this paper, Raman amplification was instrumental in bridging long spans up to 278 km with high attenuation in multi-span link configurations and minimizing the amount of nonlinearities over dispersion-shifted fibers.

References

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