White Paper

Predicting Fiber Breaks and Weak Points

Field Trial of Strain B-OTDR Using Brillouin-Based Fiber Strain Measurements over Long-Distance Aerial Cables

Aerial cables were characterized using a prototype Brillouin-OTDR. Fiber elongations were measured with 10m spatial resolution over a 152km cable and a maximal standard deviation of 0.0015%, demonstrating for the first time a test solution applicable to most telecom links.

Inroduction

Network operators need a method to proactively anticipate a break in a fiber caused by excessive strain and weakness in a cable. This is caused by weather and geologic conditions that are constantly changing the strain and temperature pressures on fiber cable. Using predictive measurements, a maintenance operations team can preserve the cable by relieving the strain or replace it proactively before transmission is lost. All-dielectric cabling solutions have been spreading fast in optical fiber networks over the recent years. Compared to metal-armoured cables, they cumulate the advantages of lower cost, lower weight, easier handling, while not requiring grounding. Yet, a lighter structure often means a lower mechanical protection and one should assess the applicability of these cables to the most demanding environments. For a fair comparison, Rostelecom has installed ADSS and OPGW ten years ago, in the north of Irkutsk. In that region, the temperature ranges from -57°C to +40°C and in cases a 10cm layer of ice may accumulate as on Picture 1-a. Over time, the cable structure may be delaminated as observable on Picture 1-b.

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Picture 1a: Ice Formation


Picture 1b: Broken strength members

With a fragilized cable structure, the inner fiber elongations can be way above the maximal value of 0.2% recommended by fiber manufacturers. Still, with the advent of bend insensitive fibers, the loss incurred may remain moderate and the data transmission operate without fault. This must not hide the fact that the fiber glass structure is not any stronger mechanically and is still likely to break at a 4% elongation. If fiber losses are no longer affected by critical levels of strain, then the traditional troubleshooting techniques shall be reconsidered.

The Brillouin spectral analysis is the sole optical characterization method capable of providing accurate distributed elongation measurements. It is well-known that the Brillouin scattering interaction has a resonant frequency that depends linearly on fiber elongation and this measurement is now widely used for fiber sensing purposes. The main difficulty with the telecom links is that they commonly exceed 100km, while a high spatial resolution is also expected to catch every strain event.

A first measurement method that may be applied is called B-OTDA. While this configuration provides the strongest signals thanks to a stimulated interaction, it is limited in distance reach due to the requirement of a loop configuration. In practice, the longest distances covered would correspond to a maximal one-way link of 80km[1,2]. Longer distances were achieved by adding optical amplifiers distributed on the line[3,4], but the maximal distance of 75km between amplifiers would not be applicable on a telecom link, not to mention the complicated non-local effects over such distances[5]. The B-OTDA does not scale to typical telecom cable installations and cannot be practically inserted to acquire a measurement without tapping the cable that exceeds 80km.

The second solution is the B-OTDR, it uses a single probe signal, launched from one side of the link. B-OTDR acquires the spontaneously backscattered Brillouin light as would a regular OTDR with Rayleigh scattering. The advantage of this configuration is evident when addressing a link with a too high budget loss or even a break: the B-OTDR will always provide information on accessible sections. The record of distance covered in a laboratory experiment was 150km, using a combination of coherent detection and Raman amplification6, but the 50m spatial resolution and the measurement accuracy at distal end would not be sufficient. Inline optical amplifier had also been proposed for BOTDR[7], but again this would not be applicable to telecom links.

In the present paper, we report on a novel implementation of a coherent Brillouin OTDR, integrated into a battery-operated field-deployable instrument. A first prototype was used to characterize an installed aerial link of 152km and 34dB total budget loss with a 10m spatial resolution. It requires two OTDR acquisitions taken from both ends of the link, but we claim this is the sole technique that is able to cover the distances of installed telecommunication lines.

Experimental setup

Our instrument uses coherent detection to selectively detect either the Rayleigh or the Brillouin spectral components of the backscattered signals. The instrument can produce regular OTDR traces for loss characterizations, exploit the Brillouin frequency shift information for strain determination (assuming a constant temperature), and it also uses the Landau-Placzek Ratio (LPR) for an independent determination of both temperature and strain[8]. Thus the user has at his disposal three types of OTDR measurements: signal loss, strain and temperature to determine the health of the fiber under test.

Results

During this test campaign, 7 fibers were tested from three sites of Ust-Kut, Kirenga and Severobaikalsk, cumulating 23 complete Rayleigh and Brillouin OTDR acquisitions, most being bidirectional. Our main results are displayed on figure 2.

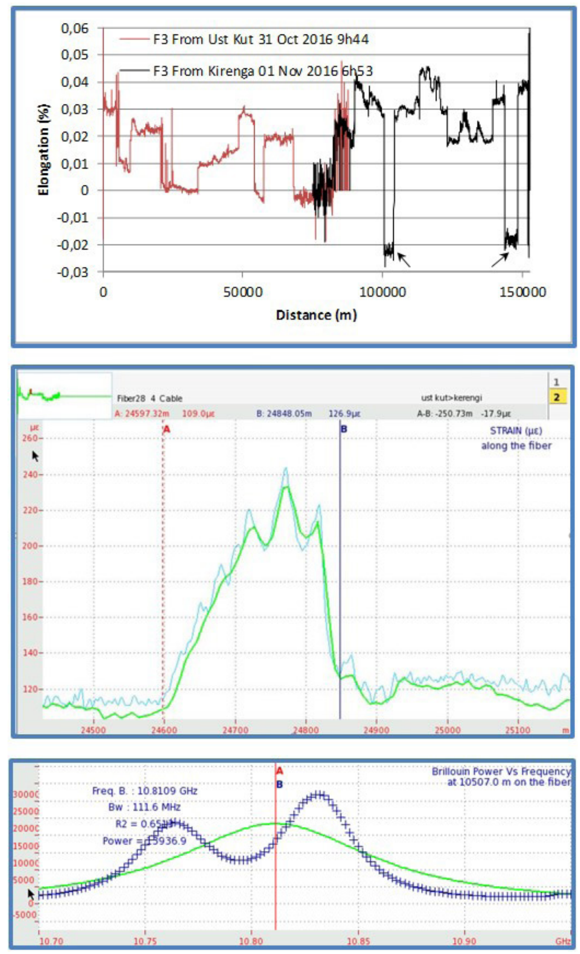

Fig. 2: a) Bi-directional strain measurement over 152km with 100ns pulse, arrows indicate sections of first generation SMF28e+.
b) Strain event recorded with 100ns (Blue) and 200ns (Green) pulses.
c) Dual-mode Brillouin spectrum of SMF28e

The figure 2-a) shows the strain as function of distance for the line from Ust Kut to Kirenga. It consists of two acquisitions from both ends, the trace from Kirenga being reverted, so to show the complete link and the good match at the midway point of the link. The succession of plateaux - each having a particular frequency shift - is typical of an aerial cable installation, where assembled cable sections are never any longer than 15km, with each cable containing several fibers from different batches. Actually, the change of Brillouin frequency shift is often easier to detect than the splice attenuation on the OTDR trace and this may be exploited. Brillouin frequency shift for a given fiber type may vary by +/-20MHz around nominal value depending of the fiber batch[9], which converts into +/-0.04% elongations. This brings a substantial uncertainty if one were to apply strictly the manufacturer's recommendation of a maximal 0.2% elongation. In that case, one would have to locate and quantify a strain event as a relative deviation from the surrounding plateau, and that would complicate the analysis. However, with the practical experience of an aerial network operated under extreme conditions, one is forced to tolerate strain events up to 3% for short durations. Assuming a combination of fibers that is as homogeneous as the one of figure 2-a), one may neglect these fiber-related changes, and let the instrument decide automatically whether the cable passes criteria based on a fixed absolute threshold.

The instrument-related uncertainties can be evaluated from the standard deviations on the various plateaux without events of the acquisition, these are typically of 0.0006%, and up to 0.0015% at the central junction point after a 17dB link attenuation.

Many of the strain profiles exhibit trains of peaks with a characteristic periodicity of 350 to 500m which is the distance between towers. Peak amplitude is typically 0.01%, with a highest level of 0.03%. These rather small values were reassuring on the current condition of the link.

One must note that events spread over fiber ranges from 150 to 400m and that measurements took place in October. Presumably strain reaches higher levels and gets more localized with ice loads, while during the summer strain gets released and spreads spatially thanks to the cable movements and thermal cycles. Nevertheless, details of the acquisitions presented are sufficiently resolved to highlight the cable weaknesses even during the summer period.

The Figure 2-b) is an instrument screenshot of a strain event showing two superimposed acquisitions taken with 100ns and 200ns pulses. While accuracy and reach are benefitting from the smoothing effect and the higher energy of a longer pulse, it obviously erases fastest details. One shall always use the best possible spatial resolution since the extent of events depends on many parameters (distribution of the load, exact cable structure and installation, gel used...).

The Brillouin spectra also allows to recognize fiber type[9], Figure 2-c) shows a dual-mode spectrum typical of the first generation of SMF28e+. That fiber was used at the occasion of repairs while a regular single-peak SMF28e had been used at installation time.

A measurement campaign such as described would only be the first step in the maintenance cycle of the cable, which may be conducted at installation or at the occasion of a troubleshooting. All subsequent measurements may be repeated the same way, but it would be recommended to use the first measurement as a reference, and produce relative data. This would remove the problem of different fibers with different frequency shifts all along the link. With the extra information brought by the LPR, our instrument can also account for the seasonal temperature variations between the two measurements. This would gain further in accuracy compared with a measurement solely based on the Brillouin Frequency Shift, and for which a +/-0.1% variation is expected over the temperature range. With a relative and temperature compensated measurement, it becomes straightforward to pinpoint the smallest evolution of the strain, using an alarm threshold that can be set to a very low value down to the instrument repeatability.

Conclusions

While B-OTDR technology has been available for a long time, we demonstrated the first field deployable instrument, that has a sufficient dynamic range to cover the distances of telecom links. Using our prototype, we demonstrated proper operation over a 152km link. Our lab tests show that 200km is accessible with a 400ns pulse width (40m spatial resolution). By the time we wrote this paper, the development was completed to include relative measurements, thermal compensation, and all the required features to fully exploit the potential of the instrument directly on site.

This solution is commercially available as VIAVI Strain B-OTDR in a portable instrument.

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