White paper

Are Networks in Emerging Markets Ready for Terabit/s Scale Optics?

Author
Sudipta Bhaumik*, Puneet Agarwal*, Prasanna Pardeshi*, Deepak Sanghi**, Praveen Kumar**,
**Sterlite Technologies Ltd, India ; **Bharti-Airtel India Ltd; ***Ciena India Pvt Ltd.*

Abstract
High speed transmission in emerging economies may suffer Optical Signal to Noise Ratio (OSNR) shortfall below today's design norms. We quantify the sources of this shortcoming on 100Gb/s to 200Gb/s transmission in one of the largest global markets for optical networks.

Key Words
Optical Fiber properties, Fiber characterization, Macro-bend loss, OSNR, Fiber optics link loss

1. Macro bends losses and its impact on fiber network

With the adoption of capital intensive 10-100 Gb/s transmission systems in many emerging markets such as India, the requirement of a predictable delivered OSNR in the outside plant is of paramount importance. In such economies, intense construction activity and poor installation practices lead to severe restrictions on predictable signal quality. Optical attenuation levels rise considerably beyond the beginning-of-life (BOL)/time of installation values. As a consequence of increased attenuation and the change in received OSNR (ROSNR), premature link failures especially at 100Gb/s – 200Gb/s and increased costs due to cable replacement are an operational reality. Service providers in these markets are challenged in the optimal allocation and utilization of network routes.

In this paper, we identify and measure one prevalent cause of such shortfalls – macrobend losses. While well understood historically, we show here that these prevalent values of increased attenuation impact the deployment of high bit-rate communications. For the first time, quantitative span loss results that are surprisingly beyond expected design values are presented for in-service optical networks. Multiple spans covering a total length of 197 km on live fiber were measured. It was found that the existence of multiple macro-bends at joint closures or fiber termination systems significantly increased the link loss in addition to other sources (splice, connector, fiber-attenuation, et cetera). Specifications with high bend tolerance relative to the ITU-T G.652.D category fiber cable are proposed to mitigate the problem [3]. The enhanced specification ensures improved life of optical fiber cable towards the deployment of 200Gb/s transmission and beyond [4].

2. Span Loss measurement of Optical Fiber Cable Link

In order to estimate the detailed loss analysis of optical fiber link, a route testing was carried out on existing long distance optical fiber route. Span loss measurement taken over a long distance route which is approximately 197 Route Km distance from Node-1 to Node-6 as illustrated in table -1. Objective of the testing was to investigate different losses in optical fiber cable link, which includes inherent fiber loss, splice loss, macro-bend loss, and basic practice of fiber and cable installation and termination.

A specialized multi wavelength OTDR which shows non reflective events or low loss events such as fusion splices and macro bends was used for the testing [5]. The event results of the OTDR are based on its predefined calculations. The basic principle of detecting the macro bend for OTDR is that the 'Splice loss doesn't vary with wavelength' whereas 'Macro bend loss varies with wavelength' [5-7]. In order to acquire an accurate macro-bend point location, multiple OTDR traces taken at different wavelengths (1310nm, 1490nm, 1550nm and 1625nm). Figure-2 shows total four macro bend locations of Link-1 (F#9), where losses vary with longer wavelength at a particular link length point. At some points, the splice losses are very high which may due to inappropriate splicing, multiple splices within very short distance (limited by OTDR resolution) and inappropriate maintenance at those points.

Based on the Bi-directional OTDR test result measurement, macro bend losses were verified for the route. Table-1 shows the testing results of the complete route, with macro bend loss and total attenuation loss details at different wavelengths. Most of these macro bends (M-bends) falls on the location of chambers which are having joint closures. Some of these macro bending can be remedied through maintenance of the fiber cable, while others may be difficult to address due to practical on-ground field challenges.

3. Field Validation of the Solution

We measured an overall 197 km of cabled optical fiber route length. The macro bend loss for overall link can be as high as 5dB at 1550 nm, which plays a significant role in link budgeting. The values of m-bend loss represent sensitivity of that particular parameter on bending loss. A new optical fiber specification was proposed as a solution is given in Table 2.

The proposed fiber is low attenuation, macro bend insensitive fiber and has very low bend loss specifications of ≤0.5dB and ≤1.5dB at 1 turn at 20mm bend diameter at 1550nm and 1625nm respectively. It ensures network is safeguarded from bends introduced resultant of unplanned events during operations of the network. The new fiber cable having similar mode field diameter at 1310 nm (i.e. 9.2 ± 0.4 μm) is fully compatible with existing installed optical transport networks fiber with regards to propagation and splicing / jointing. These specifications exceed the ITU-T G.652.D and G.657.A1 recommendations. A mid-span test was carried out, with 4kms cable and 1 turn of 20mm diameter was introduced to verify the impact of macro-bend. When standard G.652.D fiber was tested by introducing same bend condition (1 turn, 20mm diameter), the induced loss was indeed very high. Table 3 provides a comparison of measured macro bend loss of Bend Insensitive fiber v/s standard G.652.D fiber.

The macro-bend loss as measured in the field was emulated by bending fibers at different bend diameters and these were kept same for each cable samples collected from the field. Total 12 macro bend points are introduced. The relative macro-bend loss performance for cable sample A, B and a newly developed bend insensitive fiber cable over four consecutive links is summarized in Table 4. It can be seen that with bend Insensitive cable, the overall M-bend loss over four links of 197 km reduces by 82% lower than Sample A and 85% lower than Sample B, respectively. This significant reduction in macro-bend loss in network should be advantageous in terms of higher received OSNR, lower BER and or increased life time of links.

4. Lab validation of mix of 40G DP-QPSK, 100G QPSK and 200G 16QAM over Bend Insensitive fiber, standard G.652D Fiber and mix of them

High capacity transmission results with a span loss of 18.6 dB over 50 km over Bend Insensitive fiber and standard G.652.D fibers are reported here. Transmission data for 200Gb/s, 100Gb/s and 40Gb/s transmitted over a 50 km span and measurement results are summarized in Table 5. The results were repeated with standard G.652D fiber, Bend

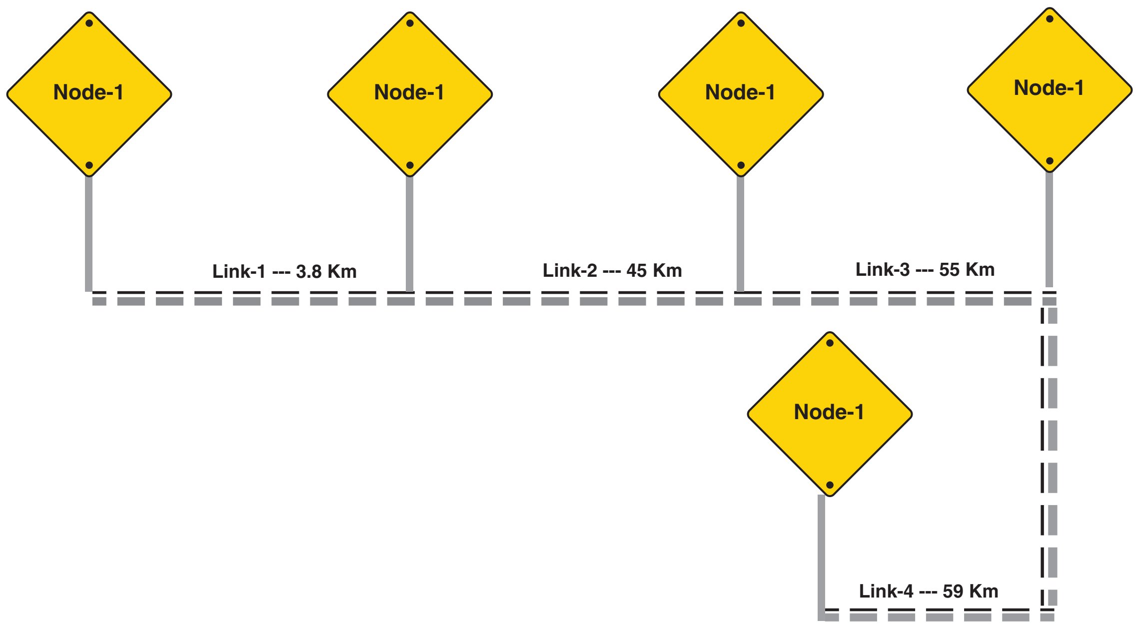

Figure 1. Long-haul link of four spans of 197 km

insensitive fiber and a mix to demonstrate that there is no adverse impact to the link in terms of received OSNR and pre-FEC BER.

5. Conclusion

We have shown here for the first time that the planned impact of macro-bends in emerging market networks can cause significant shortfall in the expected OSNR delivered in real-world networks. These macro bends have adverse impact on operational optical life time of the optical fiber cable network. The contribution of macro-bend loss in a 197 km long link was found to be around 5dB, which is significantly large and is equivalent to an additional 50-100 splice points or fiber cuts. Considering 3 cuts per thousand km per month, this loss is equivalent to 5-10 years of optical cable life. A bend insensitive fiber is proposed to safeguard the network from unplanned and incidental bends. The specification of Bend Insensitive fiber cable is compatible to all ITU-T G.652.D category fiber cable and ensures ease of deployment in all type of scenarios; contiguous as well as segmented or branching cases.

6. References

[1] Q. Wang, G. Farrell, and T. Freir, "Theoretical and experimental investigations of macro-bend Losses for standard single mode fibers", Optics Express, 13 (12), pp. 4476-4484 (2005)
[2] M. F. M. Salleh, Z. Zakaria, "Evaluation of Macrobend Loss on Long Distance Optical Ground Wire", International Journal of Engineering and Technology (IJET), 7(3), pp. 1085-90, (2015).
[3] P. Matthijsse, L. A. de Montmorrillon, G. J. Krabshuis and F. Gooijer , "Bend-Optimized G.652 compatible Single Mode Fibers", in the Proc. 54th International Wire & Cable Symposium, RI, USA, pp 327-331, November 13-16 (2005).
[4] P. Matthijsse, W. Griffioen, "Matching optical fiber lifetime and bend-loss limits for optimized local loop fiber storage", Optical Fiber Technology, 11, pp. 92-99, (2005)
[5] VIAVI White Paper: "Macrobend Detection Using an OTDR", VIAVI Viavi Solutions Inc, pp. 1-4, (2015)
[6] A. J. Harris and P. F. Castle, "Bend loss measurements on high numerical aperture single-mode fibers as a function of wavelength and bend radius", J. Lightwave Technology, 4(1), pp.34 -40, 1986.
[7] IEC 60793-1-47, "Measurement methods and test procedures – Macrobending loss", Edition 3.0 2009-03.

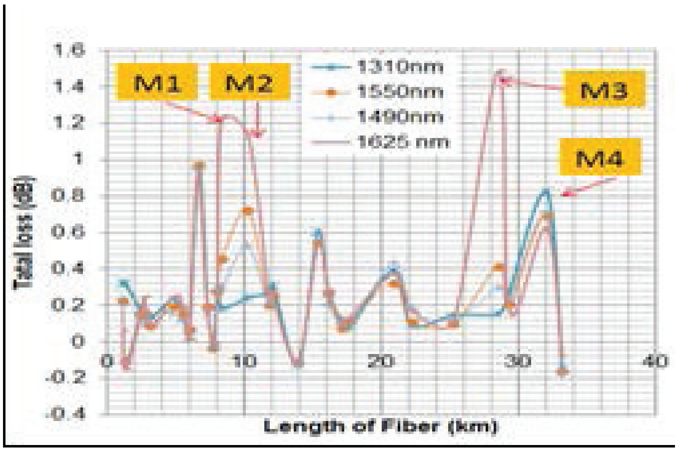

Figure 2. OTDR Trace plot measured at 1310,1490, 1550, 1625 nm

Table 1. Optical Link Loss Details

Link No.	Route	FMS Port No.#	Link length (km)	No. of M-bend	Total M-bend loss (dB)		Average M-bend loss (dB)		Average Total Span	Attenuation (dB/km) loss (dB)
					1550 nm	1625 nm	1550 nm	1625 nm	1550 nm	1550 nm
1	Link-1	F #3	37.6	none	0	0	0	0	14.55	0.39
	Link-1	F #9	37.6	4	1.22	3.78	0.31	3.10	16.37	0.44
2	Link-2	F #5	45.2	2	0.43	0.8	0.22	1.86	16.48	0.36
3	Link-3	F #1	54.7	3	1.33	1.98	0.44	1.49	17.02	0.31
	Link-3	F #33	54.7	1	0.12	0.27	0.12	2.25	15.35	0.28
4	Link-4	F #17	59.4	3	1.25	2.7	0.42	2.16	24.30	0.41
	Link-4	F #30	59.4	3	1.72	3.24	0.57	1.88	16.60	0.28

Table 2. Bend-Insensitive Fiber Key parameters

Attribute Insensitive	Bend fiber
Fiber attenuation at 1550 nm	≤ 0.19 dB/km
Mode Field Diameter at 1310nm	9.2 ± 0.4 μm
M-bend loss (1 turn 20mm diameter)	
At 1550nm	≤ 0.5 dB
At 1625nm	≤ 1.5 dB

Table 3. Measured Macro bend loss of Bend Insensitive and G.652.D fiber

Wavelength	M-bend loss (dB) (1turn at 20mm bend diameter)	
	Bend Insensitive	Standard
	fiber	G.652.D
1550 nm	0.20	0.89
1625 nm	0.64	1.91

Table 4. Comparison of macro-bend loss of different cable samples

M- bend loss at 1550 nm (dB)			
Route	**Field Cable Sample A**	**Field Cable Sample B**	**Bend Insensitive fiber Cable**
Link 1	0.32	0.36	0.06
	0.47	0.57	0.08
	0.36	0.41	0.07
	0.06	0.05	0.01
Link 2	0.29	0.31	0.05
	0.14	0.13	0.03
Link 3	0.26	0.27	0.05
	0.49	0.59	0.09
	0.59	0.75	0.10
Link 4	1.04	1.51	0.17
	0.36	0.41	0.07
	0.32	0.35	0.06
Total loss (dB)	**4.7**	**5.70**	**0.84**
Relative loss disadvantage against Bend Insensitive fiber	**+ 3.86 dB**	**+4.86 dB**	

Table 5. Measured OSNR & Pre-FEC BER for ITU-T G.652.D fiber and Bend Insensitive fiber

Channel rate	Rx. OSNR (G.652.D Fiber)	Rx. OSNR (Bend Insensitive fiber)	Pre FEC BER (G.652.D Fiber)	Pre FEC BER (Bend Insensitive fiber)
200Gb/s	33.49	33.25	2.2×10^{-3}	2.1×10^{-3}
40Gb/s	33.07	32.72	2.2×10^{-12}	4.3×10^{-11}
100Gb/s	33.53	33.22	1.3×10^{-7}	1.6×10^{-7}

7. Pictures of Authors

Sudipta Bhaumik is associate general manager at Sterlite Technologies Ltd, Aurangabad, India. He is currently responsible for application engineering of optical fiber and cable. He has over 18 years of experience in quality assurance & control, reliability & process engineering, fiber & cable manufacturing, business development, and one of the founder members of Sterlite Tech Academy. He joined Sterlite in 1998 as process development engineer at its optical fiber plant. He holds a B.Tech degree in ceramic technology from Calcutta University, India and master's degree in ceramic technology from Indian Institute of Technology, Banaras Hindu University, India. He is an ASQ certified Six-Sigma Black Belt, Manager of Quality/Business Excellence and Quality Auditor and is active in telecom standard development organizations like ITU-T, IEC, BIS. A frequent author of technical papers, white papers and application notes, he twice (2002 and 2003) won the Urbain J.H. Malo Award for best division presentation in WAI's convention.

Puneet Agarwal is chief manager at Sterlite Technologies Ltd, Gurgaon, India. He is a solution architect of telecom transmission network both for active and passive equipment. He brings more than 13 years of experience in transmission network planning, solution specialist, and technical sales from the top telecom multinational and Indian Indigenous companies. His career has focused on delivering quantifiable results for his employers and clients in the way of network services integration, product success and customer loyalty. He earned a bachelor's degree in Electronics and Communication field.

Prasannakumar Pardeshi is deputy manager at Sterlite Technologies Ltd, Silvassa, India. He is currently responsible for application engineering role in optical fiber cable business. He has over 23 years of experience in copper and optical fiber cable manufacturing, quality assurance, customer support and one of the founder members of Sterlite Tech Academy. He joined Sterlite in 1994 at its copper cable manufacturing plant. He holds a Bachelor of Science degree from NMU Jalgaon University, India.

Badri Gomatam joined Sterlite Technologies Ltd in 2011 as the CTO in the Telecom Business unit. He has over 20 years of product development, marketing and business development experience in high speed Integrated Circuits and Optical Communications. At Sterlite he leads the newly established Center of Excellence focused on product development and research in optical fiber communication. He received his Ph.D. in 1993 from the University of Massachusetts, Amherst, in Electrical Engineering. Prior to Sterlite he was based in the United States, most recently with ClariPhy Communications.