STL

Whitepaper

Improved Optical Network Performance Using Stellar Fibre

Author
Arvind K Mishra, Pramod Mishra and Shekhar Saxena

Introduction

The Fibre Optics network infrastructure is highly immune to electromagnetic waves and provides unlimited bandwidth to transport data and voice signals at a very high rate, over extremely long distances. [ref. 1]. This makes it a suitable communication channel to support a large number of network architectures: FTTH, FTTx, Data centre interconnect, Access/Metro/Long distance networks, smart cities infrastructure and wireless backhauling for 4G and 5G networks.

But like any other network infrastructure, fibre networks too are susceptible to disruption due to external factors such as fibre cuts and surge in span loss caused by accidental fibre/cable bends or operational abuse. The increase in span loss reduces signal strength at receiver and increases probability of receiving bit errors. This increases packet loss and leads to call drops or temporary or permanent link failure till abuse is arrested.

Until abuse is rectified, this impacts quality of service (QoS) and quality of customer experience (QoCE). Therefore, the network operators need a superior optical fibre technology that allows them to build networks which are resilient to disruptions and help them to deliver a superior experience to customers as well as to control operational expenses and improve their bottom line [ref. 1].
As we move towards the backbone of the optical network link, it has been observed that there are several operational issues that arise due to abuse during installation or during repair & maintenance, specifically at the cable joint-closure by accidently bending fibre beyond its designed specifications. As a result, there is a significant increase in the macro-bend loss and overall link or span loss. The increase in span loss either reduces the optical signal to noise ratio (OSNR) or reduces the optical signal power received at the destination receiver which results in increased Bit-error ratio (BER), one of the key signal quality performance indicators.

Higher BER leads to increased packet loss, which causes a consequent increase in packet re-transmission leading to higher latency and a decline in network throughput. The entire fibre link might go down if the BER increases beyond the critical level of soft-decision (SD) and hard-decision (HD) forward error correction (FEC) limit. The net result of such a disruption is degradation in network quality and call drops.

On the other hand, if the macro-bend loss varies temporarily because of accidental pulling/ bending of cables beyond their recommended limit, such abuse may lead to significant fluctuation in optical power across network links which can potentially damage the network equipment and reduce its lifetime.
In this paper, we present a comparative network performance of G.652.D [ref. 7, 8] and Stellar [ref 10] fibre. The case study would demonstrate the effectiveness of Stellar fibre in preventing network disruption as well as its compatibility with high data rates, such as 100G, 200G, and 400G systems. Our study concludes that Stellar fibre is the best solution to build the most reliable and resilient optical fibre networks.

Network Disruption Challenges

Fibre optic technology is traditionally considered the safer option for Tera-scale data transmission without interruptions as long as it is deployed by adopting the best practices [ref. 2]. Fibre optic networks routinely get disrupted due to civil works such as road expansion, landslides, upgradation, or maintenance of utility infrastructure (Gas, Water, Electricity pipelines) etc. Addressing fibre or cable cuts in such cases has been challenging due to unorganised mechanical diggers, improper cable pulling etc. Due to lack of skilled manpower, other numerous factors arise such as incorrect splicing and maintenance processes.

The sharp bends during digging and pulling of optical fibre cable by mechanical excavators result in the disruption of the network due to an instantaneous increase in macro-bend loss and overall link loss. The network disruption can be temporary or permanent and it may take hours or even days to track down the exact abuse location and repair the fault. Several optical fibre network abuse scenarios for the disruption have been shown in the Fig. 1.

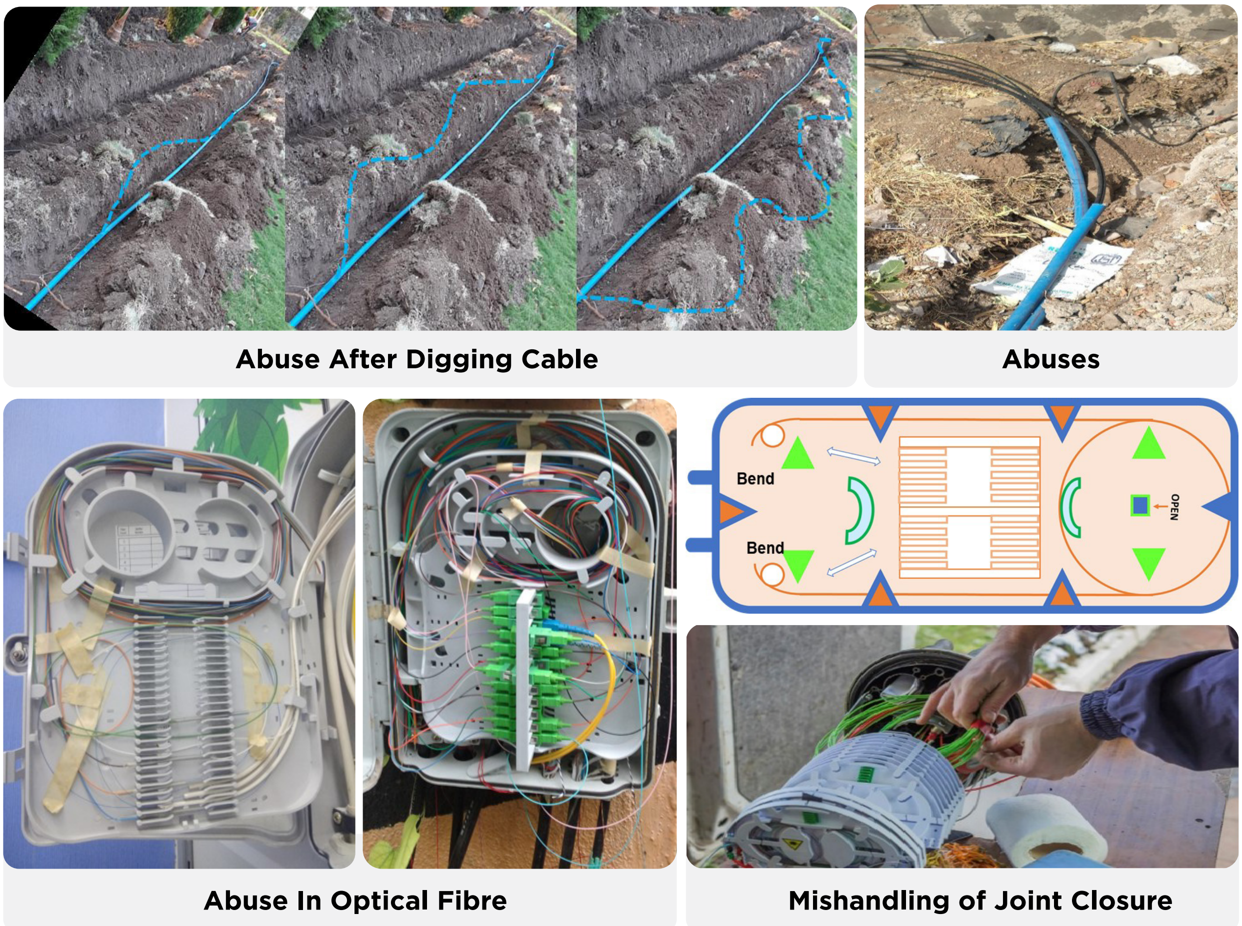

Fig. 1*: Optical fibre network disruption scenarios*

At the point of joint in an optical fibre cable the core of the cable on each side is spliced and a splice protective sleeve is carefully placed in the joint-closure's splice holder. The additional coated fibres are put inside the splice tray with a loop diameter larger than 30 mm [ref. 3] as shown in Fig. 1. However, if this is not done properly, some of the extra fibre in the splice tray can form a tighter loop or a sharp edge with a bend diameter lower than 20 mm.

In such a scenario, the standard G.652.D category fibre would experience significant increase in the macro-bend loss and can potentially disrupt optical signal transmission [ref. 3]. This can severely impact the network information delivery quality (high call drops of voice and higher packet loss for data traffic) thus requiring an urgent repair response to arrest origins of data outages.

With the use of bend insensitive fibre such as G.657.A2 [ref.9], the macro-bend issue can be reduced. This range of optical fibres has a lower Mode Field Diameter (MFD) than the G.652.D category fibre. During repairs, in case of adding G.657.A2 fibre to the legacy networks which are built using G.652.D fibres, there will be higher splice loss due to a significant difference between the MFD of G.657.A2 and G.652.D fibre. Therefore, for the reduction of these network disruptions a good understanding of optical fibre waveguide design is critical.

Comparison: Macro-bend performance of G.652.D and Stellar Fibre

A bend in optical fibre results in disruption of the modal guidance properties in the core and clad region differently. Therefore, the optical fibre suffers radiation losses at the bends. After going through extensive research and development efforts, scientists at STL have developed a unique optical fibre solution to address the above network disruption challenges.

“Stellar” optical fibre is an enhanced version of G.652.D standards [ref. 7] with matched MFD, but at the same time offers superior macro-bend loss performance, similar to G.657.A2 [ref. 9] fibre. The radiation losses out of the clad region were measured using visible laser at 1 turn bend diameter of 15 mm,20 mm and 30 mm for G.652.D [ref 8] and Stellar fibre. The results are as shown in Fig. 2. It was noticed that Stellar fibre has negligible radiation loss in comparison with G.652.D fibre.

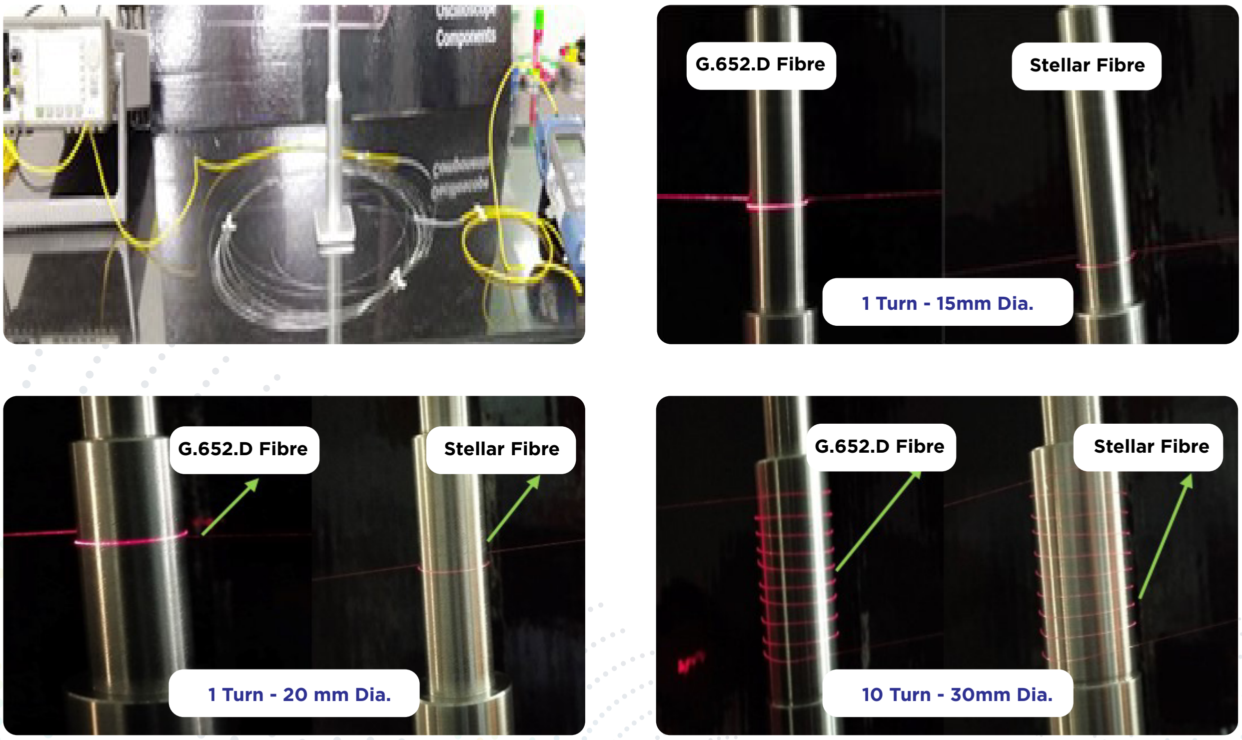

Fig. 2: *Visible radiation loss due to Macro-bend in G.652.D and Stellar fibre*

The corresponding macro-bend loss performance of G.652.D and Stellar fibre at 1550 nm are shown in Fig. 3. The macro-bend loss increases exponentially with lower bend diameter and linearly with the number of turns. It was found that on a logarithmic scale, at a lower bend diameter, particularly 20 mm and 15 mm, Stellar fibre has a very low macro-bend loss, typically ~1/10th of G.652.D. Therefore, by replacing G.652.D with Stellar fibre in the existing networks, operators would be able to mitigate signal degradation and network disruption to a great extent.

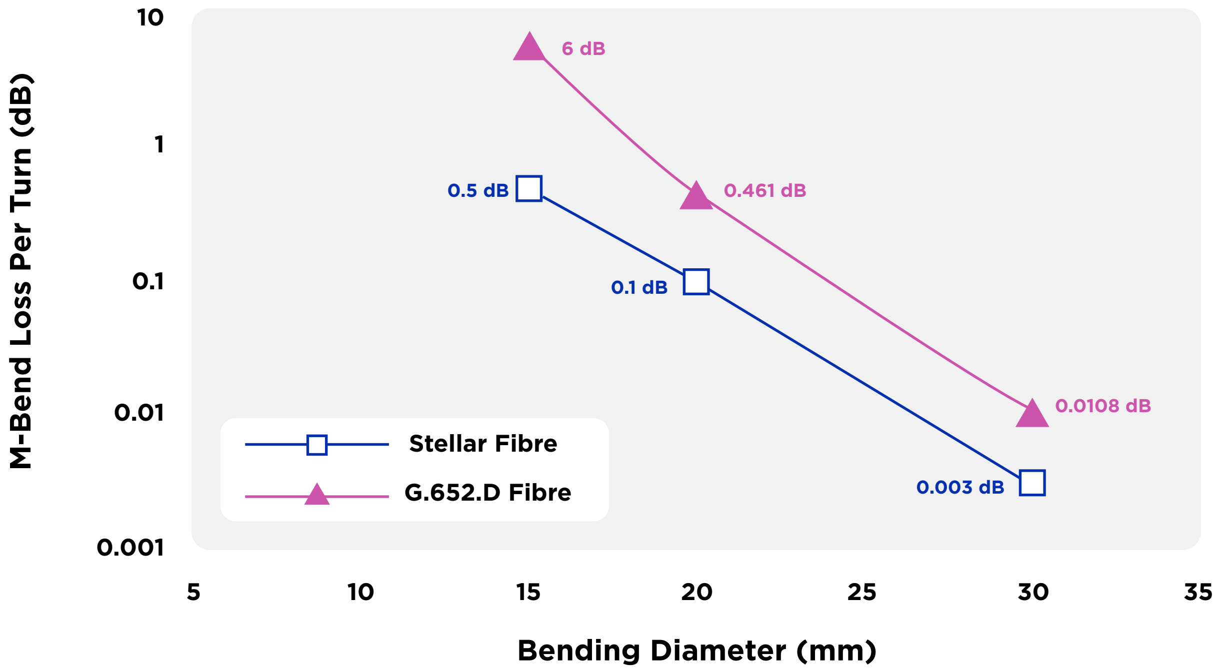

Fig. 3: *Measured macro-bend loss versus Bend diameter for G.652.D and Stellar fibre*

Impact of Macro-bend loss in 100G/200G/400G optical fibre link

As the demand for data guzzling applications such as video streaming & Ultra High Definition TV, AR&VR grows, the network capacity needs to keep pace with this growth. There is an urgent need to build additional network capacity in the access, metro, and long-haul optical transportation systems.

The polarization multiplex single carrier based transceivers are under deployment to achieve ultra-high capacity such as 100G (DP-QPSK@32 GBd), 200G (DP-16-QAM@32 GBd), 400G (DP 64-QAM@32 GBd) and 800G with multi carrier options and can easily be integrated in Multi-Terabit DWDM systems over long distance with cascade of optical amplifiers (EDFA).

The evolution of data transportation speeds in edge networks beyond 100G, 200G and 400G transmission systems will bring major changes and execution complexity [ref. 6]. As the data rate increases with higher order modulation format such as 100G, 200G & 400G, the essential optical signal to noise ratio (OSNR) will also increase due to increased number of constellation points per symbol and the limited effective number of bits (ENOB) of ADC/DAC beyond 32Gbaud, receiver noise and DSP processing complexity) [ref.4].

The received OSNR can be increased by either increasing the launch power or by reducing the span loss or with the availability of very low noise figure (NF) mid-span amplifiers. In the analytical approach, the empirical received OSNR after transmission over fibre can be defined as:

Rx_OSNR = 58 + Launch Power per channel - NF - Span Loss - 10 log (# span) - Nonlinear Penalty

Where, NF = Noise Figure and

Span Loss = Fiber attenuation + Splice Loss + Connector loss + Macrobend loss

However, in DWDM systems, the OSNR also reduces due to fibre non-linearity and strongly depends on the channel launch power. With higher channel power, nonlinear penalty is expected to be larger. For this analysis, we have assumed 70 km as the typical span of a commercial long-distance network (which covers 80 - 90% of global links). Therefore, the expected span loss would be in the range of 15 - 19 dB, including the connector loss with an average typical fibre attenuation of 0.2 dB/km.

In order to compensate for the span loss of all DWDM channels, the commercial wideband Erbium Dope Fibre Amplifier (EDFA) are employed with a dynamic gain range of 15 - 25 dB. In this approach, launch power per channel and the NF has been taken as 0 dB and 6.5 dB, respectively. In a large number of operator networks, it was found that year-on-year the span loss increases at a very high rate and the links fail to meet transmission requirements when span loss exceeds maximum gain of EDFA (25 dB).

After extensive measurements in several operator networks, it was concluded that unexpectedly high losses were found at the cable joints consisting mainly of macro-bend loss caused by accidental tight bending of fibre in the splice tray. The increase in span loss due to incremental macro-bend loss can reduce the OSNR below the threshold level required for an error-free reception of signals at the destination. The portion of span loss due to macro-bend effect strongly depends on the bending diameter of the fibre and the number of turns.

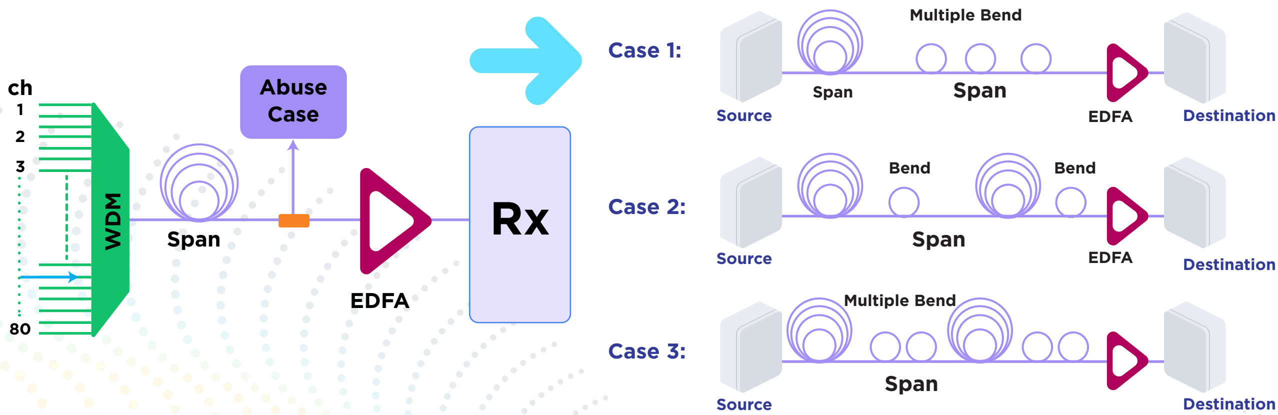

Fig. 4: *Schematic diagram to emulate practical operation abuse due to existence of macro-bend at multiple locations or single locations with multiple turns*

Any increment in span loss reduces the OSNR and increases the BER resulting in higher packet loss or call drop. We have conducted an analysis of the impact of macro-bend loss over one span optical link of 70 km fibre. The OSNR was estimated by simulating practical scenarios of operational abuse with single turn at multiple locations or multiple turns (up to 5 turns) in a single location or combination of both.

The analysis was conducted with G.652.D and Stellar fibre, in links without bends and with bend diameter of 15 mm and 20 mm at different turns as shown in Fig. 5. For both the fibre types , the span loss without any macro-bends was estimated to be 19 dB with the OSNR of 32.5 dB at the receiver. The span loss primarily consists of fibre attenuation of 70 km length, connector loss and splice loss (@ 4km cable segment). The overall span loss and the corresponding OSNR of optical links with G.652.D and Stellar at bend diameter of 15 mm and 20 mm, with up to 5 turns at single location or one turn at 5 locations, are summarized in Table 1.

It was found that in all the cases the measured OSNR was lower in the case of G.652.D fibre than Stellar fibre. At a bend diameter of 15mm with 5 turns, for G.652.D fibre, the OSNR was observed to have to 5.5 dB from 32.5 dB as compared to 30 dB for Stellar fibre under similar conditions. This demonstrates an advantage of significantly lower macro-bend loss in Stellar fibre over G.652.D fibre, making it more suitable for optical networks.

Table 1: Calculated Span loss, OSNR and BER for 100G, 200G and 400G systems at fibre bend diameter of 15 mm and 20 mm with G.652.D fibre and Stellar fibre, respectively

# turn @15mm	G.652.D Grade Fibre					Stellar Fibre				
	Span Loss (dB)	OSNR (dB)	BER @ 100G	BER @ 200G	BER @ 400G	Span Loss (dB)	OSNR (dB)	BER @ 100G	BER @ 200G	BER @ 400G
0	19	32.5	Error Free	Error Free	Error Free	19	32.5	Error Free	Error Free	Error Free
1	25	26.5	Error Free	Error Free	1.00E-03	19.5	32	Error Free	Error Free	Error Free
2	31	20.5	Error Free	1.50E-03	Link Down	20	31.5	Error Free	Error Free	Error Free
3	37	14.5	4.00E-04	Link Down	Link Down	20.5	31	Error Free	Error Free	Error Free
4	43	8.5	Link Down	Link Down	Link Down	21	30.5	Error Free	Error Free	Error Free
5	49	2.5	Link Down	Link Down	Link Down	21.5	30	Error Free	Error Free	Error Free
# turn @20mm	Span Loss (dB)	OSNR (dB)	BER @ 100G	BER @ 200G	BER @ 400G	Span Loss (dB)	OSNR (dB)	BER @ 100G	BER @ 200G	BER @ 400G
1	19.461	32.04	Error Free	Error Free	Error Free	19.1	32.4	Error Free	Error Free	Error Free
2	19.922	31.58	Error Free	Error Free	Error Free	19.2	32.3	Error Free	Error Free	Error Free
3	20.383	31.12	Error Free	Error Free	Error Free	19.3	32.2	Error Free	Error Free	Error Free
4	20.844	30.66	Error Free	Error Free	Error Free	19.4	32.1	Error Free	Error Free	Error Free
5	21.305	30.20	Error Free	Error Free	Error Free	19.5	32	Error Free	Error Free	Error Free

The BER for a single carrier 100G (DP-QPSK), 200G (DP-16QAM) and 400G (DP-64-QAM) coherent system was measured using reference [ref 4, 5] as shown in Fig. 5 and summarized in Table 1. If the value of pre-SD-FEC BER reaches more than 2x10-2, all the error bits cannot be corrected and as a result packets are received as an error and retransmission is required. If the link is unable to receive any error-free data packets even after repeated transmission attempts, then it can be treated as a link failure since no information can be received successfully.

It was found that BER performance of fibre links with G.652.D fibre can support error free signal if there is minor operational abuse and if bend diameter is 20 mm or larger. However, the links could fail at a bend diameter of 15 mm even for 100G, with a single turn at more than 3 places.

For 400G transmission system, the optical link can produce very high packet loss (as not all error bits can be corrected) even with a single turn at a single location, making G.652.D fibre unsuitable for future proof networks with 400G and beyond. On the other hand, with the Stellar fibre link, the error-free performance can be achieved for all data rates including 100G, 200G and 400G signal or multi-carrier 800G even in case of reduced bend diameter of 15 mm and with more than 5 turns.

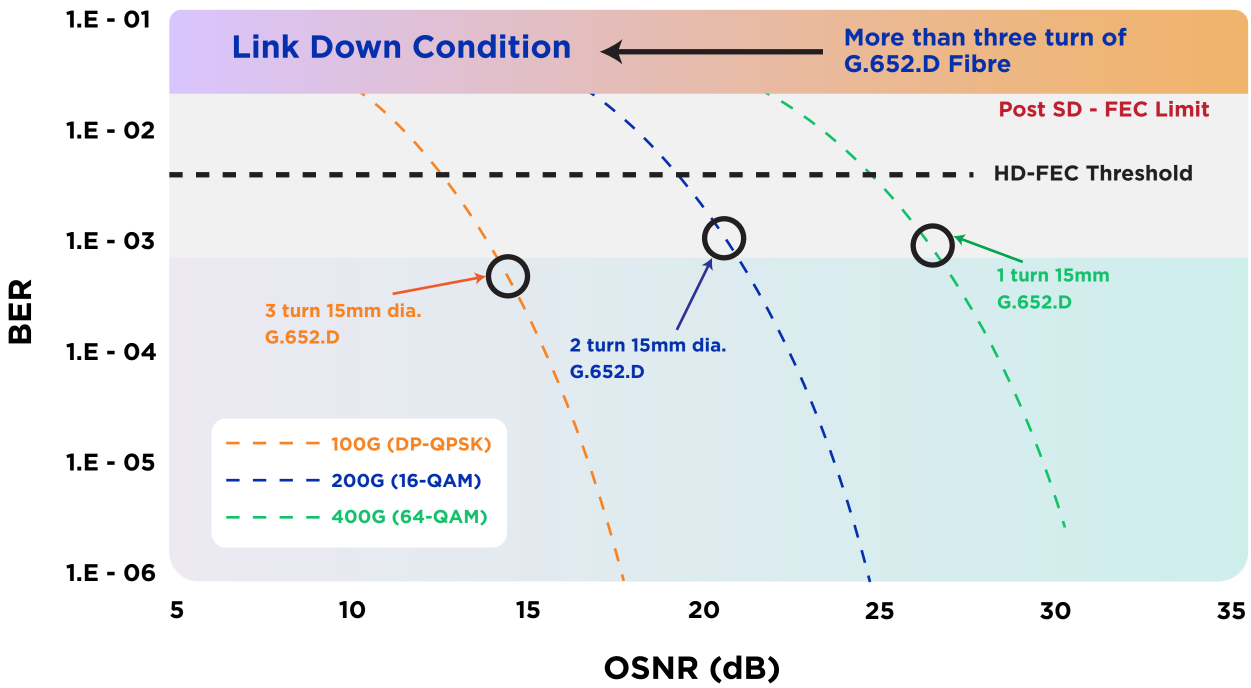

Fig.5: *Expected BER, OSNR after 100G, 200G & 400G transmission over 70 km span at different number of bend of 15mm diameter with G.652.D and Stellar fibre [4,5]*
(https://www.inphi.com/pdfs/400GbsSingleCarrier.pdf)

Recommendations

Service providers across the world are looking to quickly upgrade their 10G to 100G data networks to higher speed with 200G transmission systems while preparing migration towards 400G and beyond solutions in their networks. In this paper, it was concluded that with the superior bend insensitivity characteristics, **Stellar fibre** which offers the same MFD as G.652.D fibre, can handle the abusive environment better as compared with G.652.D fibre. Therefore, it will improve network quality, enabling superior service delivery in terms of reduced call drop or packet loss, increase in call set-up success rate, decrease in congestion due to enhanced network throughput, lower latency and longer life time of the optical network link.

Stellar fibre is the biggest breakthrough for network operators, which overcomes the challenges posed by accidental operational abuse during network roll-out and maintenance. Furthermore, it will help improve the bottom-line and help support high capacity transmission systems with 200G, 400G and future proof multi-tera-scale network technologies with superior resilience and reliability of network links.

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