Technical Study on the Viability of Hollow-Core and Ultra-Low-Loss Silica Fibres in Metro-Core Optical Networks

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Abstract: We numerically compare the performance benefits and viability of deploying hollow-core-fibre (HCF) and ultra-low-loss (ULL) fibre in metro-core optical network considering practical traffic growth, limitations of transceiver OSNR and output power from commercial optical amplifiers.

1. Introduction

The benefits of hollow core fibre (HCF) over standard single mode fibre (SSMF) in terms of loss, nonlinearity, dispersion, latency and thermal stability are well known [1]. The outstanding lowering of the attenuation of HCF in the recent years, especially using the nested anti-resonant node-less fibre (NANF) architectures, has prompted the discussion of deploying HCF in both the terrestrial and subsea optical networks [2]. However, the transmission performances are constrained by practical power limits from the power feeding equipment in submarine system [3] and commercial optical amplifiers in terrestrial networks [4] and transceiver noise [5].

The recent growth of high-speed coherent optical pluggable modules such as QSFP-DD based 400ZR has enabled low-cost, flexible and interoperable point-to-point DCI and metro networks using IP over WDM architectures. The OIF have recently standardized 400ZR and also been working towards 800G coherent pluggable specifications targeting 80-120km amplified, single span, DWDM links. The newer versions of 400G pluggable modules i.e., 400ZR+, OpenZR+ can extend the reach of 400ZR to regional distances and provide flexible line-rate and modulation by adopting high-performance oFEC at a cost of lower power efficiency.

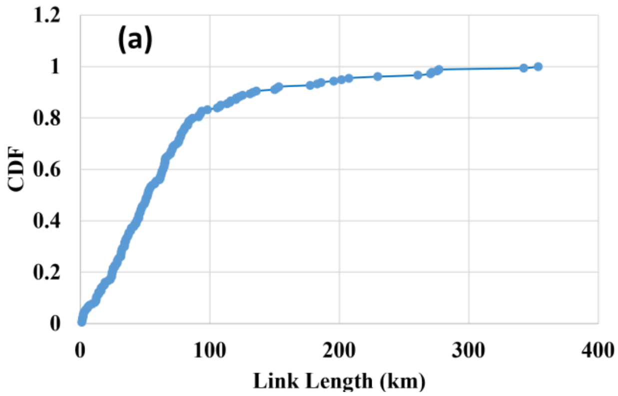
HCF can extend the reach of 400G pluggable modules much longer than SSMF based links, allowing fewer number of in-line amplifiers in the network and improved energy efficiency. However, the maximum available optical power from commercial erbium doped fibre amplifiers (EDFAs) (20~23dBm) and low transceiver OSNR limit the theoretically achievable benefits from HCF in point-to-point metro-core optical networks. Silica core based ULL single mode fibres also have the potential of improving the link OSNR, however higher chromatic dispersion (CD) than SSMF will limit the maximum link length of 400ZR.

Here, we use Gaussian Noise (GN) model to numerically demonstrate the performance comparison of HCF and ULL fibre with deployed SSMF in BT's backbone network considering practical traffic matrix with 30% annual traffic growth in next 10 years. We consider up to C+L band point-to-point DWDM transmission with 400ZR/ 400ZR+ pluggable modules and total optical launch power up to 23dBm. We report that, comparable HCF and ULL performance in terms of total number of in-line amplifiers, however lowering the loss to 0.05dB/km can enable a repeaterless point-to-point national backbone network in BT, allowing huge benefits in terms of power consumption and costs. The higher OSNR using HCF enables a simpler and energy efficient point-to-point network using mostly the 400ZR modules and use of future 800G pluggable optics in a greater number of links than SSMF and ULL.

2. Reference Network and System Setup

BT fibre network is considered here for the numerical modelling. The network consists of 106 sites including 10 hubs, 3 internet peering points (IPPs) and 180 links. Each site is connected to one of the hubs and separately to two IPPs with resiliency. All the nodes in the network are linked with one or more G.652 fibre pairs including the maximum, minimum and average link lengths of 353.5, 1.1 and 67.9 km, respectively. The distribution of the link lengths is given in Fig. 1(a) with > 80% links are less than 100km showing a relatively small sized network compared to US core networks where the impact of HCF is expected to be different. The peak demand is assumed to be ~27.9Tb/s in the current year (2022) with 30% year-on-year growth in subsequent 10 years.

For modelling the network, a point-to-point network is considered where IP routers are connected with either 400ZR or 400ZR+ optics, depending on the calculated OSNR of the worst channel and accumulated dispersion per link. The required OSNR threshold for the 400ZR and 400ZR+ are 26 and 24dB. The traffic between the source and destination passes through intermediate IP routers with traffic aggregation facilities from multiple sources. The IP traffic routing across the network is carried out by a bespoke multi-layer modelling tool using a pair-diverse, minimum hop routing algorithm, taking into account the fibre connectivity and IP level demands [6]. Then, a



Parameters	SSMF	ULL	HCF
Attenuation (dB/km)	0.25	0.152	0.174
Dispersion (ps/nm/km)	17	20.2	2
Dispersion slope (ps/nm^2-km)	0.067	0.06	0
Nonlinear refractive index (m^2/W) $\times 10^{-20}$	2.96	2.1	2.52×10^{-3}
Core diameter (μm)	10.4	12.1	34.5
Raman gain coefficient (W^{-1}km^{-1})	0.43	0.3	0.4×10^{-3}

(b)

Fig. 1. (a) Distribution of link lengths in the modelled network; and (b) Fibre parameters used in the GN model.

resilient network design has been obtained by allocating peak demand traffic over two diverse paths. Finally, the total aggregated traffic on each link and the number of 400G transceiver modules are calculated once the demands are served across the network. Note that additional network capacity is installed to provide resilience.

The GN model takes the traffic matrix and calculates the total OSNR of all the channels in each link considering amplified spontaneous emission (ASE) noise from the amplifiers, nonlinear interference (NLI) including the inter-channel stimulated Raman scattering (ISRS) and transceiver noise [7]. The fibre parameters used in the model are given in Fig. 1(b). Here, G.652, HC-DNANF (Double Nested Antiresonant Nodeless Fibre) [8] and Corning® Vascade EX2000 are considered as the existing deployed fibre, HCF and ULL variants, respectively. Two attenuation coefficients of HCF are considered as 0.174 dB/km (DNANF [8]) and a future lower loss at 0.05dB/km. The transmission bandwidth, transceiver OSNR, channel bandwidth and spacing are considered as 9THz across C+L band, 30dB, 60GHz and 100GHz. First, the optimum launch power of each channel is determined by calculating the maximum total OSNR at increasing total powers up to 23dBm. Then, an OSNR threshold of 24dB is chosen for the worst channel to determine the minimum number of spans in each link, Once the OSNR of all the channels are calculated for the optimum span length and launch power in a link, the type of 400G pluggable modules is then determined depending on the OSNR of the worst channel and accumulated CD for each fibre type. For example, 400ZR based link should have all the channels with OSNR $\geq$ 26dB and accumulated dispersion $\leq$ 2400 ps/nm as described by OIF. The accumulated dispersion limit of 400ZR+ is considered higher than that of accumulated over the maximum link length in the BT's network for all the fibre types. Once all the peak traffic demands are served with appropriate transceiver types and OSNR are calculated for all the channels at optimum span lengths, the number of links which could have been upgraded with 800G coherent pluggable (i.e., future 800ZR) are also calculated and the total number of such pluggable modules are counted considering 29dB OSNR threshold and 2400 ps/nm accumulated CD limit. Finally, the overall reduction of 400G pluggable modules is counted for all the fibres.

3. Results and Discussion

The total number of in-line amplifiers, 400ZR, 400ZR+ and 800G coherent pluggable are calculated in the modelled network in each year using all three types of fibres: SSMF, ULL and HCF following the rules described above.

In Fig. 2(a), a significant drop in number of required in-line optical amplifiers can be observed using both the ULL and HCF, thanks to lower loss and nonlinear properties compared to deployed SSMF. HCF with 0.174dB/km requires lower number of in-line amplifiers up to year 5 and then shows comparable performance with the ULL. The improved performance in the initial years is due to available higher power per channel due to lower traffic load per link in the network. As the traffic demand increases, the OSNR performance improvement in HCF gets restricted by the available input power per channel and transceiver OSNR. Interestingly, no in-line amplifier would require if HCF with 0.05dB/km loss is deployed in the network even with very high peak traffic demand in year 10. In Fig. 2(b), HCF (0.174dB/km) can significantly reduce the use of 400ZR+ by 93.8% and 92.1% in year 10 compared to SSMF and ULL, respectively, thanks to higher received OSNR and low accumulated CD. Lowering the HCF loss to 0.05dB/km allows all the links to be served by power efficient 400ZR pluggable modules. The reduction in total number of 400ZR+ modules using ULL is only 21.6% (year 10) with respect to SSMF and that is mainly due to the higher CD value (20.2 ps/nm/km), irrespective of having much lower loss and nonlinear coefficient than SSMF.

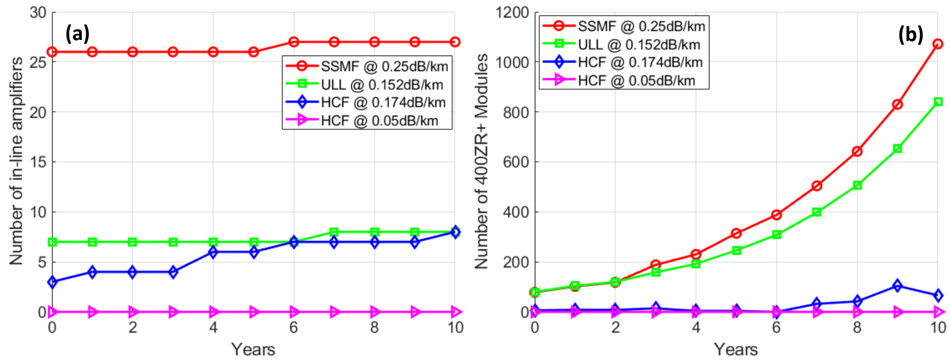


Fig. 2. Comparison of (a) Total number of in-line amplifiers per years; (b) Total number of deployed 400ZR+ modules per year.

In the modelled network, the point-to-point links with ≥ 29dB OSNR for all the channels can be served by future 800G coherent pluggable optics providing spectral efficiency and potential reduction in the number of parallel C+L band system in highly congesting links. In Fig. 3(a), the received OSNR of all the channel of the 81.09 km link with year 10 traffic demands is shown with 63x400G channels, where the HCF and ULL scenarios can use 800G pluggable modules to support the same demand because of having >29dB OSNR. The total number of 400G transceivers reduction in such possible links are also calculated in all the fibre types and the improvement compared to currently deployed SSMF is shown in Fig. 3(b), showing the increasing benefits of HCF over SSMF and ULL with increasing traffic demands. The lower loss HCF at 0.05dB could not improve the reduction much higher than that of 0.174 dB/km HCF due to input signal power and transceiver OSNR restrictions as described earlier.

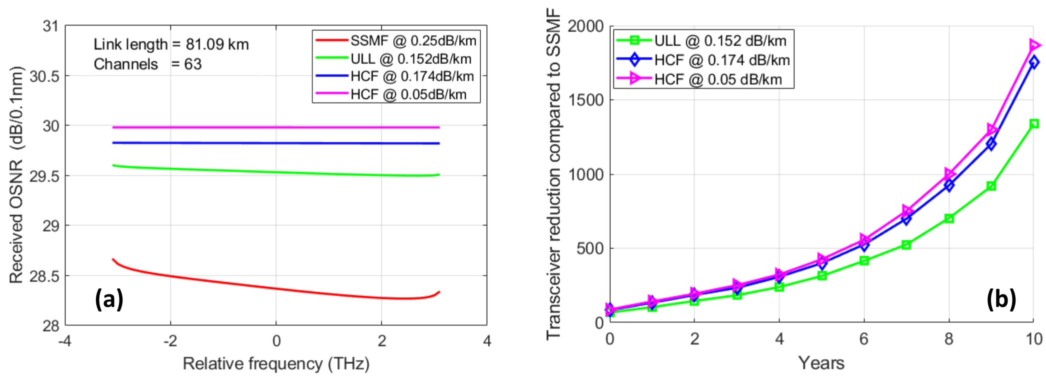


Fig. 3. comparison of (a) calculated received OSNR in a link with year 10 traffic; and (b) 400G transceivers reduction compared to SSMF.

4. Conclusion

Here, we numerically demonstrate the performance and benefits of HCF and ULL silica fibre in BT's core network with realistic traffic growth. We report that, the maximum input signal power and transceiver OSNR constraints in metro-core optical networks put a limit to maximum achievable benefits from HCF even with much lower loss. HCF shows comparable performance with industrially mature ULL fibre in terms of total number of in-line amplifiers. However, the much lower CD of HCF enables power efficient 400ZR pluggable modules in most part of the network. Additionally, HCF allows future 800G coherent pluggable modules replacing the 400G ones in greater number of links than SSSM and ULL due to high available received OSNR (≥ 29dB) for all the channels, providing significant reduction of number of 400G pluggable modules and IP router ports.

(This work is supported by the EU's Horizon 2020 research and innovation programme under grant agreement No. 101016663 (B5G-OPEN).)

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