A Telecoms Operator Perspective on Hollow Core Fibre

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Abstract *Solid silica fibre has fuelled telecommunications for ~45 years. The development of hollow core fibre offers a radical alternative, creating an opportunity to refine networks further. We consider the practicalities of scale deployment and consider the use in the access network.*

Introduction

As the data rate in solid silica fibres has risen from the Mbit/s reported in 1978 [1] to the Tbit/s of today, the increase in speed has required the underlying, silica-induced impairments to the optical signals to be addressed. From Erbium Doped Fibre Amplifiers (EDFAs) to overcome silica attenuation, to Digital Signal Processing (DSP) to compensate for silica's dispersion, new technology has allowed data growth to continue. Hollow Core Fibres (HCF) lower these silica-induced impairments considerably. We consider how this could affect our networks, in particular the access network.

Hollow Core Fibre, Current Performance

HCFs are split into two main types: Photonic Band Gap (PBG) and anti-resonant. Both are now commercially available in environmentally robust cables, and both have been deployed in the field [2,3]. The main anti-resonant design, Nested Anti-resonant Nodeless Fibre (NANF) has the lowest measured loss and the lowest theoretical loss. This has resulted in links of up to 40km of NANF HCF being deployed for commercial applications [4]. As the light is guided in air, we benefit from flat Chromatic Dispersion (CD) of around 2-3ps/nm/km, a latency reduction of ~1.5µs per km, 1000x lower nonlinearity, high optical power handling, low thermal sensitivity and in some areas, lower attenuation than standard silica-based fibres. These parameters are well documented [5]. Two parameters that do not currently outperform SMF are Polarisation Mode Dispersion (PMD) and Intermodal Interference (IMI). PMD has reported measurements of ~0.4ps/√km [6] which is a significant increase from the ITU G.652.D 0.2ps/√km standard. IMI has been measured between −45dB/km & −55dB/km [7], a meaningful improvement from the original designs at -35dB/km. PMD can be addressed by DSP techniques if required, whilst IMI is only limiting for ultra-high-capacity long-haul systems. A 5-10dB improvement in IMI is all that is required to increase total throughput to 2-5 times that of SMF [8].

Operational Challenges Now Addressed

The switch from a solid core to a hollow one comes with some changes to field deployments. Operators need robust solutions for widescale field use, namely:

1. Interfacing to existing equipment
2. Field splicing of HCF to HCF
3. HCF to HCF & HCF to SMF connectors
4. Low bend sensitivity
5. Field fault management

In terms of 1-3, attenuation of the signal is always the first concern, but as Table 1 shows, losses have been managed to an acceptable level.

Parameter	Commercial	Academic Tests		Ref.
	SMF-SMF	SMF-HCF	HCF-HCF	
	dB	dB	dB	
Fusion Splice	0.05 Average	0.44	0.16	9,10,11
Fixed Adapter	-	0.15	-	12
Connector	0.05 Min 0.1 Typ	0.10	0.13	13,14

Table 1. Reported losses of HCF connections (all types)

The standout results are the 0.10 dB loss for a SMF to HCF connector and 0.13dB for HCF to HCF connector. This is in the same range as a SMF connector and although this is a laboratory experiment using conjoined tube HCFs (anti-resonant type), this shows that low loss interconnects are possible. The reported return losses of solid to hollow interconnects are in the region of 35dB [14] for an unoptimised connection; but recently an angled adapter version achieved 40dB [15] and a connector version 45dB [16]. Compared to the >55dB we routinely expect for solid fibres this is modest. But these SMF to HCF connections will usually be in the central office when connecting to equipment and so only used at end points. So, reflections should only be a problem on short links.

Fusion splicing in the field is required when installing cable segments or repairing a cable cut. Fusion splicers with increased diameter holders are required due to the overall increased size of the HCF fibres, but apart from this, no other specialisation over standard fusion splicers is required as orientation of the two joining fibres does not have to be aligned. Losses are palatable at ~0.16dB shown in PBG-HCF.

Using these prototype figures, a typical 40km link made up of a worst case of 2km cabled sections could have twenty splices and two SMF to HCF adapters, creating a manageable extra 1-2dB loss compared to a similar SMF link.

Cables are required to go through underground ducts, whilst fibres need to be stored in splice trays when connecting cable sections. This can introduce macro bending losses to a link. PBG HCFs are robust to bending, showing little loss down to 10mm diameters. NANF HCFs are more sensitive, the bend loss being linked to the type of nested tube design [17]. For example, a simulation of the DNANF structure optimized for 1550nm operation has a 0.05dB excess loss for a 20cm diameter or 100mm radius bend [18]. This is in comparison to the commonly used G.657.A1 and G.652.D fibres which can have bend radii as small as 15mm and 30mm respectively for a similar performance [19]. In conclusion, operators will need to have an increased splice tray size to reduce bend loss and will need to assess routes to minimise any bends to the cable.

Finally, Optical Time Domain Reflectometers (OTDR) are commonly used to commission and fault find on standard SMF in the network. The absence of any significant Rayleigh backscatter in HCF creates issues when using standard equipment in the same way. But research has shown [20] that an EDFA amplified standard OTDR with a 30dB dynamic range is capable of spatial resolutions of 1.5m using only 30 second averaging. This indicates promise for the use in the field for fault resolution.

Data Transmission

Operators have traditionally used the Ordinary or O (1260 to 1360nm) band for shorter access links, due to the zero-dispersion window at ~1300nm, allowing low-cost transmission with no requirement for CD compensation and simple transmit and receive optoelectronics. The Conventional or C band has generally been used for longer links. This is due to the low attenuation window centered at 1550nm, coupled with the availability of optical amplification in the form of EDFAs. Now, with HCFs and the commercial availability of amplification in the O band [21], the traditional divide may be over. For an operator this could lower costs in access links by using high volume, lower complexity components over longer distances, without or reducing digital signal processing. In addition, access links in the UK are becoming longer as central offices are reduced from 5600 to ~1000 locations [22]. This increase in access distance and sensitivity to cost make it an attractive area to consider HCFs.

For example, current commercial 400G optics using PAM4 and the O band, switch from 4 x 100G λ to 8 x 50G λ at >10km and are then limited to 40km before a switch to C-band coherent operation. The cost and technology complexity, as we step up the reach range, is illustrated in Fig 1.

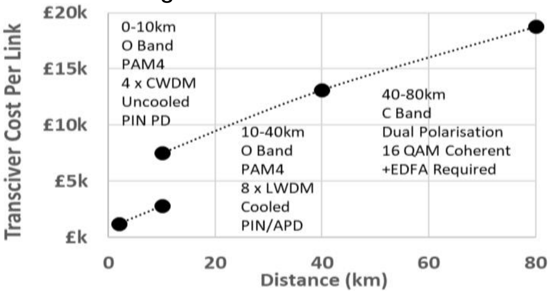

Figure 1 Costs and technology at 400G (source: fs.com)

HCF has a proven lower loss [23] than SMF of 0.22dB/km at 1310nm and a theoretical loss of <0.10dB [17] between 1320nm and 2µm. This would allow the existing transceivers to reach longer distances based on attenuation and reported power budget alone. See Fig 2.

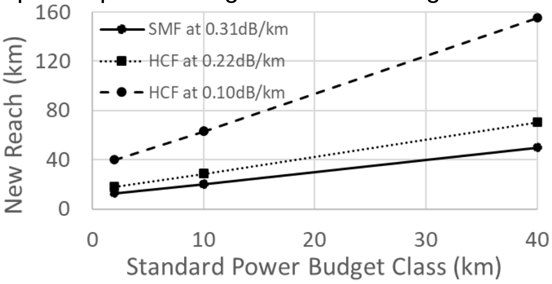

Figure 2 Power budgets of 400G transceivers at HCF/SMF

In SMF it is the CD power fading that limits the reach of the optics in the O band [24]. The amount of CD and its slope across the wavelengths limits the reach in Wavelength Division Multiplexing (WDM) transmission. For example, calculations [24] in SMF show that the 1320nm wavelength can support ~5.4 times longer reach than that of the 1360nm wavelength, due to the variation of 3.1ps/nm/km of CD between them. In HCF this is relaxed. NANF has a simulated CD of only 2 to 3ps from 1200 to 1400nm, a ~1ps/nm/km variation over 200nm of bandwidth. In comparison, standard SMF has -5 to 4ps/nm/km CD at 1260 nm to 1360 nm, half the bandwidth and nine times the variation (Fig 3.)

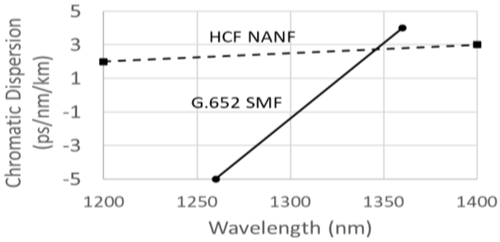

Figure 3. Comparison of CD in HCF-NANF and SMF

This ability of HCF to increase reach has already been proven in the C band. A NANF with a measured CD of 2.1ps/nm/km was shown to be able to support a 12.5GHz, 3dB bandwidth over a 100 km distance [25]. This allowed PAM4 modulation for 4×50Gb/s over 120km and 4 ×100Gb/s over 38km.

Access is cost sensitive, and it is assumed that the lower the attenuation of a HCF, the lower the manufacturing yield and hence the higher the cost. A simple power budget calculation shows that a ~0.19dBkm O band loss in NANF would allow the current 8 x LWDM 50G 40km class transceivers to reach 80km, well within the CD fading window of 120km demonstrated. Thus, removing the need for coherent optics. The 4x100G 10km CWDM transceivers would need a 0.15dB/km HCF loss to hit the 40km reach window. This shows a dilemma: a high-cost cable could allow the higher volume (<40km) links to reduce equipment costs, yet a more attainable attenuation would reduce the costs of the lower volume longer (40-80km) links. The settling point of cost / attenuation will be crucial to scale use.

Attributes for Radio Access Networks (RAN)

The previous section showed that high-speed low-cost optics could be enabled by HCF. RAN will require this; can HCF also help in other ways?

Low Latency: A RAN lower layer split using eCPRI moves complex processing deeper into the network at the Distributed Unit (DU) with low-cost Remote Radio Units (RRU) at the edge. The depth that this processing can take place is limited by the Hybrid Automatic Repeat reQuest (HARQ) latency. The minimum HARQ latency of 100µs in SMF restricts this distance to a theoretical maximum of 20km [26]. But HCF can increase this physical reach, whilst keeping the latency the same. Tests showed a 7.2 Low layer split RAN being pushed out to 43km [27]. As shown in Fig 4, this can lower costs by allowing a higher geographic coverage from a single central office, more RRUs from one DU.

A second use of the low latency could be to improve RAN resilience. To protect the network from outages in DU's, alternate RRUs can be parented from an adjacent DU. This allows coverage to be maintained in an area in the event of one having an outage. This increases the fibre length, but unfortunately it still needs to be within the HARQ latency described earlier. The latency of HCF at ~3.5µs/km gives an increase of ~30% in length for the same latency budget as SMF. This allows the adjacent central office to be further away and so reduces the number needed to cover an area.

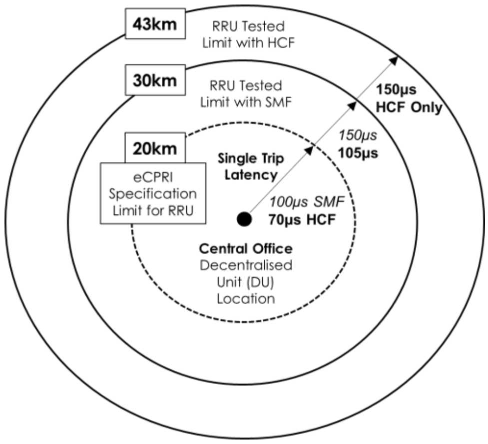

Figure 4. eCPRI reach extension using HCFs lower latency.

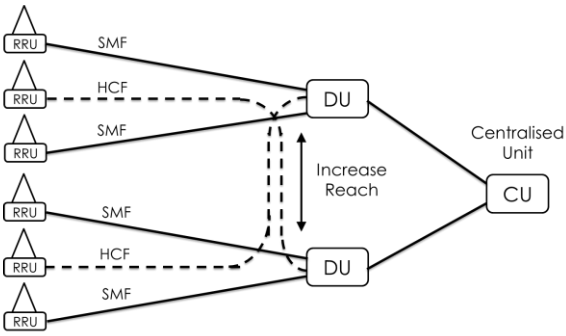

Figure 5. RAN DU resilience using HCFs lower latency.

High Power: The RAN is a vital national infrastructure, but vulnerable to natural disasters. Double clad fibres have been proposed for remote powering of antennae to protect against outages [28]. These have been shown to handle 150W of optical power, delivering up to 44W of electrical power. Full time remote powering is not attractive due to low Conversion Efficiencies (CE), with ~30% end to end CE being typical. But, as a fallback during electrical grid outages this could offer critical resilience. A 1kW optical beam has already been proven over a 1km NANF [29]. This is a realistic level for practical RANs as they will require kWs of power. For example, a 4 port MIMO system using 4x40W will consume ~1kW in non-sleep mode [30]. The theoretical power handling capability of NANF is ~3kW of output optical power [29] over 5km, giving the ~1kW electrical power required with the CE already demonstrated. An additional aspect is that HCF should allow simultaneous transmission of the data over the same powering fibre due to the inherent low nonlinearity, creating a single fibre solution. This has not been demonstrated yet.

Conclusion

Solutions for the scale use of HCF in the field are available and ready for industrialisation. HCF can enable access transmission to be reduced in cost whilst RAN operations could be enhanced.

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