Technologies to Scale Cable Density for the Next Decade

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Abstract *Capacity and distribution requirements in networks drive a need for more fibre in cable. However, the space available to provision additional fibre is constrained leading to higher density of fibre in cable. This paper will describe fibre technologies under consideration to achieve this aim. ©2023 The Author(s)*

Introduction

Today, telecommunications networks are faced with a demand for capacity that is increasing at 30-35% CAGR [1,2]. Often, capacity increases are delivered by advances in optical transmission design using increased bandwidths, digital signal processing and higher bit rates. In todays advanced optical systems, a single optical fibre could carry; 90 wavelengths at 800 Gbits per second in coherent transmission schemes that use digital signal processing to overcome transmission impairments, such as dispersion and optical amplification to overcome fibre attenuation [3]. However, even in the most advanced systems the efficiency of optical equipment upgrades is diminishing as capacity improvements approach the Shannon's limit. [4]

Whilst capacity is increasing in networks, distribution is also increasing. The number of devices connected to IP networks will be more than three times the global population in 2023, as many more people, places and machines get connected by fibre. [5]. Distribution networks are often characterized by low fibre counts in distribution, coupled with higher fibre counts in feeder networks. Single point fibre connections feed into network cores that expand with the increase of tributary connections; much like a stream and river system.

In some applications, such as carrier access feeder networks or data centre interconnects (DCI), the need for distribution to many end points in the network and an emphasis on power and cost means that serving capacity requirements is often more economically achieved using more fibre in a cable. This is particularly true where the system is to be installed on a green-field route.

The need for network capacity and distribution has placed a focus on the amount of fibre that can be delivered within a constrained space or weight of cable. There are significant advantages to be gained from a high density of fibre in cable across all applications.

Density

In the context of optical fibre cable for telecommunication networks, fibre density is often described as fibres/mm^2 or cores/mm^2. The advantages of density of fibre in cable can be realised in two ways.

1. Higher fibre/core counts in the same space, increasing the reuse of existing duct infrastructure.
2. Same fibre/core count in a smaller outer diameter cable (OD) with less weight reducing transit costs and improving cable handleability.

In both cases the efficient use of materials in dense cables can lead to a lower carbon footprint cable for the required fibre count and reducing complexity in transit with smaller and lighter cables that are easier to handle [6].

Achieving density of fibre in cable, today.

Achieving high density of fibre in cable is an involved engineering task. The densely packed fibre must maintain optical performance across a wide range of operating temperatures and maintain mechanical performance during installation. [7]

In order to achieve higher density of fibre in cable, whilst maintaining optical performance some fibre manufacturers have developed low OD fibres with a smaller cross-sectional area than traditional 242 µm fibres. Optical fibres at a low OD of between 200-180 µm are available today. [8]

Fibres in dense cable environments can incur bend-related loss from both macro and microbend mechanisms [8]. Low OD fibres have therefore also been designed with an ITU recommendation G.657 specification [9] to ensure the optical performance of dense cables across a range of operating temperatures. [10]

The highest density optical cables have up to 11.5 fibres/mm^2, achieved using 180 µm OD fibre and a microduct cable construction. Microduct cables are the highest density cable constructions available today. These cables have

Fig. 1: Left: Microduct bundle configurations with micro cables. Right: Standard 1.25" duct with a standard loose tube cable. Increases of more than twice the fibre in the same space can be achieved with microduct bundles and micro cables.

a lower tensile strength than traditional loose tube cables and are designed for jetting into small microducts using a cushion of blown air to support the progression of the cable through a small microduct. By bundling together a number of small microducts it is possible to assemble very high fibre count corridors of multiple fibre cables in a high density package, as illustrated in Fig 1. These constructions support both higher capacity using high fibre counts, and also distribution with many small cables of single fibres. The use of micro cables in microducts can more than double the fibres in the same footprint as a standard duct installed with a standard loose tube cable.

As fibre counts and density of the fibre within the cable increases the ability to identify individual fibres becomes a more challenging task. In micro cables and other loose tube cable designs, fibre is grouped within tubes, so that fibres can be identified in sub groups. Tubes can hold upto 36 fibres with each fibre identified by one of 12 colors and subsequent 12 fibre groups identified by both a color and a single or double ring mark identifier.

Very high fibre counts of 3,456 and 6,912 fibres in a cable can be found in some Data Center applications. Density is a requirement in cable of this type because of the need to reduce the size and the weight of the cable for practical installation. Furthermore, the number of fibres brings challenges in splicing and identification. Mass fusion splicing is a technique that has been used for many years to simultaneously splice multiple fibres, grouped in a ribbon, at one time. In its original format ribbon fibre was laid flat within a fixed matrix structure. In recent years a rollable ribbon format has been used in which the fibres are held together by matrix dots [11] This allows the fibres to collapse and roll into available space within a dense cable format. Ribbon of this kind can be both single spliced and mass fusion spliced.

The use of ribbon fibre allows for easier identification of sub-groups of 12 fibres where each fibre is colored for identification.

Advanced fibres for increased density.
The industry has been focused on advanced fibres that can enable the next evolution in density of fibre cores within a cable.

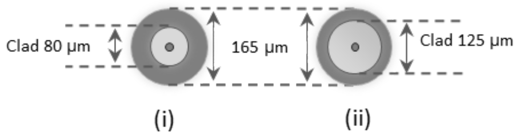

Fig. 2: Very Low outer diameter fibre structure (i) low outer diameter achieved using reduced cladding diameter and (ii) low outer diameter achieved using reduced coating.

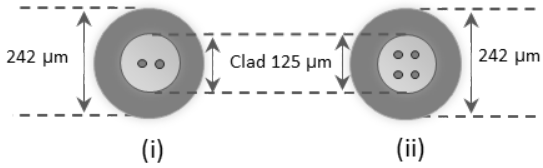

Fig. 3: Multi-core fibre example structures (i) 2 core multi-core fibre example with linear arrangement (ii) 4 core multi-core fibre in a 2x2 array arrangement

Two significant candidates have emerged as enablers of the next step change in density of fibre in cable, for the next decade and beyond;

1. Very Low OD fibres, shown in Figure 2. with ODs of less than or equal to 165 µm, achieved using reduced coating around a standard 125 µm clad fibre or using a reduced cladding core (of around 80 µm OD), with a standard coating layer. These fibres offer a 50% reduction in cross sectional area compared with a standard 242 µm fibre, offering opportunities for further density increases in cable. [12]
2. Multi-core fibre, shown in Fig 3. are fibre structures that contain many cores with a cladding of 125 µm. Up to 19 cores have been demonstrated in a single fibre strand [13]. The density increase in cable is proportional to the number of cores in the multi-core fibre. The arrangement of the cores can be linear or array based, depending on the connectivity requirements.

Very low OD fibres

Fibre OD specifications are governed by the IEC 60793-2-50 [14] Currently specifications limit the minimum size of a fibre for outside plant cable applications to 180 µm. However in some compelling cases, such as in Data Centre applications, where both capacity and distribution requirements within a small amount of space are extreme, a reduction in fibre OD may be justified to achieve the required densities.

The current eco-system of optical communication systems is built around a standard 125 µm cladding in fibre, for this reason a reduced coating very low OD fibre may be preferred over a reduced cladding fibre. Furthermore, as discussed earlier, a bend resilience characteristic in fibres for density is desirable to avoid bend-related loss in cable. Reduced clad fibres have proved less tolerant to microbend than 125 µm clad alternatives due to their smaller glass diameter. [15] Cable OD could be reduced by a third using a 165 µm reduced coating OD fibre, with a 50% reduced cross sectional area when compared with a standard 242 µm fibre. In practise cable design factors require a bend resilience feature in the fibre to avoid bend related loss in the cable and maintain compliance with attenuation requirements.

Reduced cladding fibres, on the other hand, provide more coating protection and are specified for very short reach intra-connection fibres for high-density connectivity in data centre subsystems [16].

Multi-core fibres

The inclusion of multiple cores within a single fibre strand offers opportunities to significantly increase the density of cores within a single cable. In these cases, the density will scale with the number of cores, on the condition that the fibre bend resilience can accommodate the specific cable design. Multi-core fibre experiments have demonstrated that the characteristics associated with specific glass profiles are largely unaffected by their inclusion in a multi-core fibre form factor [17]. This means that glass profiles with bend resilient features, within a multi-core fibre format should be able to accommodate dense cable designs and their inherently more challenging environment for fibre. Multi-core fibre designs, however, bring with them challenges in cross talk and manufacturing. Multi-core fibres of various designs and formats are the subject of active development in the industry but are yet to be standardized or used extensively in commercial systems.

In addition to the design features required for practical operation and manufacture of these types of advanced fibres, the use of multiple cores in a single fibre represents an eco-system change in fibre splicing and connectivity. Fibre splicing has now been demonstrated across multiple laboratories with the use of active alignment systems [18]. Fibre fan-out components, that convert multiple cores of the fibre into single fibre outputs are also in use in demonstrator systems. [19] Other components, such as multi-core fibre optical amplifiers are under development [20]. The development of a viable eco-system is essential for the implementation of large scale, terrestrial, multi-core fibre systems that can deliver density with economic and practical viability.

Conclusions

Density of fibre in cable is delivered by a combination of reduced fibre geometry and bend resilience alongside cable design. The practical implementation of very high fibre in cable density relies upon the use of appropriate installation techniques and the existence of a viable eco-system in connectivity and components.

Achieving density using existing components and techniques relies upon fibres compatible with an existing eco-system that is built around a 125µm cladding, single core fibre. Micro-cable designs that can be installed in microducts using jetting techniques deliver the highest density cables available today. The combination of low OD fibre and micro cable designs provide users the ability to deliver both capacity and distribution into today's advanced optical networks. In high fibre count cables ribbon fibres provide the ability to use mass fusion splicing to deliver reduced installation and repair times. Ribbon formats provide sub-groups that, in addition to colouring allow for identification of fibres in the cable.

Where network capacity requirements exceed what can be delivered by a single core fibre, multi-core fibres provide hope of even higher densities of fibre cores in cable; but rely upon the development of a viable eco-system for practical implementation.

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