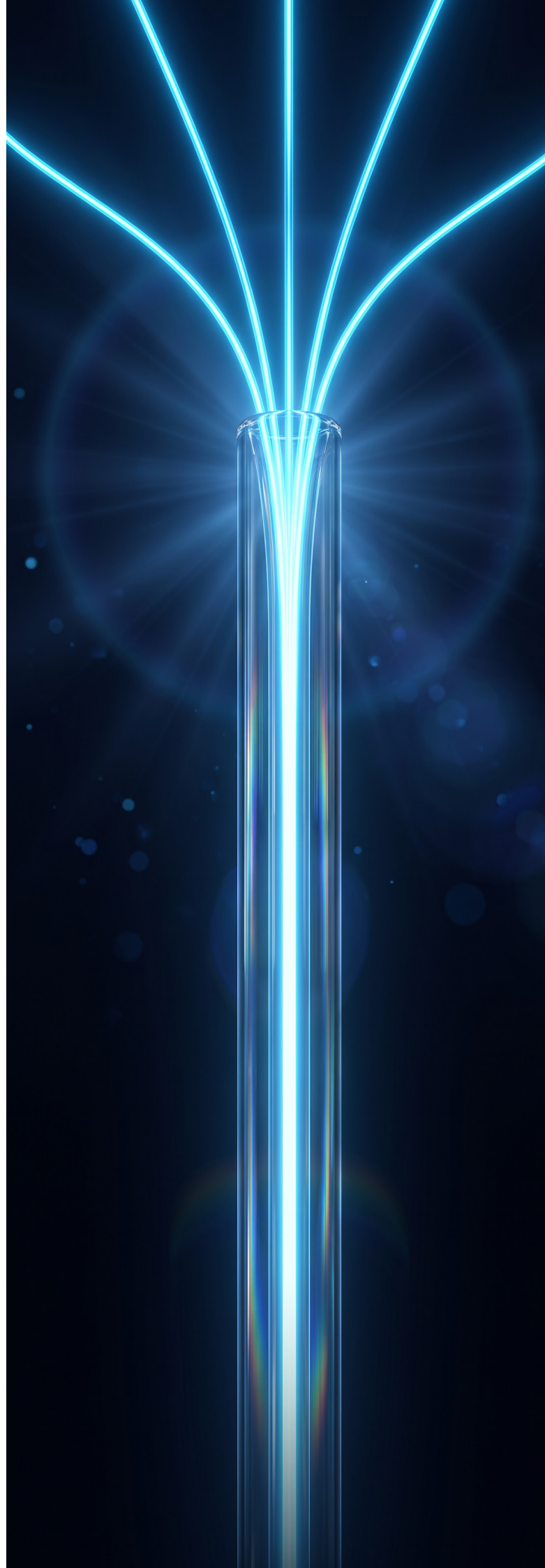


Densifying optical networks

Understanding space division multiplexing technologies

From reduced-diameter fibres to multicore fibres: increasing optical capacity without proportionally increasing physical footprint

White paper



Optical networks are entering a new phase of densification

For decades, network capacity has primarily increased by transmitting more data through each optical fibre. Higher symbol rates, advanced modulation formats, wavelength-division multiplexing and the use of additional spectral bands have progressively expanded transmission capacity. These approaches remain essential, but they no longer address every infrastructure constraint.

As cloud, artificial intelligence, high-performance computing, mobile networks and data-centre interconnection generate more parallel optical links, network operators must manage not only bandwidth, but also physical density. Available space in ducts, cable pathways, racks, patch panels and optical interfaces is becoming an increasingly important design consideration. **The strategic question is therefore evolving: how can more optical paths be deployed within a limited physical footprint?**

Space Division Multiplexing, or SDM, provides a family of responses to this challenge. It increases the number of optical transmission paths available within a given space. This can be achieved by integrating more conventional fibres into a cable, reducing fibre dimensions, introducing several cores within a single fibre, or using several propagation modes within one core.

These approaches offer different combinations of density, maturity, compatibility and complexity. Reduced-diameter fibres can increase cable density while preserving much of the existing transmission ecosystem. Multicore fibres can provide several spatial channels within a single fibre, creating an additional level of densification. Few-mode and combined multicore/few-mode architectures may offer even greater spatial multiplicity, while requiring more extensive adaptations in components, connectivity, signal processing and test methods.

However, spatial density alone is not sufficient to define a viable solution. The real value of SDM must be assessed at system level. Optical performance, cabling behaviour, connectivity, splicing, measurement, reliability, installation, interoperability, economics and environmental impact must all be considered.

Industrialisation will therefore be decisive. A promising fibre design only becomes an infrastructure solution when its optical and mechanical performance can be maintained through manufacturing, cabling, installation and operation. Cable design plays a critical role in translating advances in optical fibre technology into solutions that can be reliably deployed in real networks.

For operators, hyperscalers, data-centre owners and infrastructure providers, SDM should not be viewed as a single technology or an immediate replacement for conventional fibre. It is a portfolio of complementary approaches that can address different capacity and space constraints, depending on the application, the required level of compatibility and the maturity of the surrounding ecosystem.

Through this white paper series, ACOME Group aims to contribute an industrial and educational perspective to the development of next-generation optical infrastructure. The objective is to clarify the available technology paths, identify the conditions required for industrialisation and support informed dialogue across the optical communications ecosystem.

The next frontier of optical infrastructure will not be defined by transmission capacity alone. It will be defined by the ability to transform spatial density into reliable, scalable and deployable connectivity.

THREE MESSAGES TO REMEMBER

- 01 A changing constraint**
The challenge is shifting from bandwidth alone to bandwidth and physical density.
- 02 A portfolio of options**
SDM is a family of technologies, not a single optical architecture.
- 03 A system-level test**
Industrial value must be demonstrated from fibre and cable to connectivity, installation and operation.

1. The new challenge for optical networks

Key takeaway

Increasing network capacity is no longer only about transmitting more data through each fibre. It is also about deploying more optical paths within the available physical infrastructure.

1.1. Growth is no longer only about bandwidth

The expansion of artificial intelligence, hyperscale cloud and high-performance computing is reshaping optical-network requirements. Network evolution has traditionally been described in terms of bandwidth. That remains important, but it is no longer sufficient: distributed architectures, compute clusters, storage systems and data-centre interconnections also require a rapidly growing number of parallel optical links.

Growth therefore creates a dual requirement:

- carry more data on each link;
- deploy more optical paths between systems and locations.

This second requirement places direct pressure on the physical infrastructure: ducts, pathways, racks, patch panels, interfaces and the resources required for installation and maintenance. In data-centre interconnection environments, interface density becomes particularly important when hundreds of fibres or more must converge between sites and towards increasingly compact optical interfaces.

1.2. From transmission capacity to spatial capacity

Understanding SDM requires a distinction between two complementary dimensions.

Transmission capacity

The amount of data transported by a channel or fibre. It can be increased through higher channel rates, advanced modulation, coherent digital processing, improved spectral efficiency, wavelength-division multiplexing and additional spectral bands.

Spatial capacity

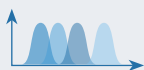
The number of optical paths integrated into a fibre, cable, duct or interface. It can be increased through more conventional fibres, smaller-diameter fibres, several cores in one fibre, or several propagation modes in one core.

The distinction is fundamental. In some networks, the primary constraint is the maximum capacity of each fibre. In others, including metropolitan, access and data-centre interconnection networks, the limiting factor may instead be the number of available paths within a restricted space.

KEY LEVERS TO INCREASE TRANSMISSION CAPACITY



Higher
channel rates



Improved
spectral efficiency



Advanced
modulation



Wavelength-division
multiplexing

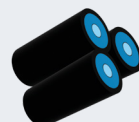


Coherent digital
processing



Additional
spectral bands

KEY LEVERS TO INCREASE SPATIAL CAPACITY



More
conventional fibres



Smaller-diameter
fibres



Several cores
in one fibre



Several propagation
modes in one core

2. Why traditional approaches face practical limits

2.1. Increasing throughput per fibre

Transmission systems continue to use conventional fibre more efficiently. However, further gains become progressively more demanding because of nonlinear effects, optical-power constraints and the usable spectral bandwidth. When these factors become limiting, spatial parallelism provides an additional lever: adding an optical path can increase the aggregate capacity available to the system.

Why can't we increase a fibre's capacity indefinitely?

For years, wavelength division multiplexing (WDM) has been widely used by multiplexing wavelengths and successively opening up several spectral bands (C, then L, S, etc.). This technique is now approaching its physical limits: a channel's capacity depends on the available bandwidth and signal quality, the improvement of which is constrained by Shannon's limit. In practice, a conventional single-mode fibre caps out at around 100 Tbit/s per fibre. SDM therefore adds another lever: the number of spatial paths utilised in parallel.



To learn more about optimising transmission over single-core optical fibres (low-attenuation fibres with a large effective area, such as G.654.E), see the dedicated ACOME Group white paper.

Key takeaway

When adding cables or increasing cable diameter is no longer practical, spatial density becomes an additional design lever.

2.2. Adding fibres and cables

The most direct response to increasing demand is to deploy more fibres or more cables. This approach benefits from a mature ecosystem, but it also increases physical space, material use and operational workload. Three broad strategies can be compared:

- add several cables of unchanged capacity;
- increase fibre count and cable diameter;
- increase spatial capacity through SDM while seeking to limit cable footprint.

The first two strategies may eventually saturate existing ducts or require larger cables. The third seeks to increase the capacity of the cable and the duct without a proportional increase in physical footprint.

2.3. Different applications, different bottlenecks

The value of SDM varies depending on the main challenge facing the infrastructure: it lies in its ability to address the primary bottleneck in each network.

Application environment	Primary SDM opportunity
 Long-haul and submarine	Increase aggregate transmission capacity while controlling cable diameter and energy efficiency.
 Metropolitan networks	Add optical paths inside existing, often constrained or saturated ducts.
 Access and mobile fronthaul	Support more distributed connection points and service convergence.
 DCI, AI data centres and HPC	Increase link and interface density where space is a primary constraint.

3.

SDM: a family of responses to density

An optical infrastructure can be described as using SDM when it increases the spatial density of fibres within a given cross-section and/or increases the number of spatial channels within a common optical cladding. This leads to two broad approaches.

3.1.

Densifying physical fibres

The objective is to integrate more independent fibres into a cable or interface. **Relevant approaches include reduced-coating-diameter fibre (RCDF), reduced-cladding fibre (RCF) and very-high-density cable architectures** such as ribbon-based designs or nanomodule® constructions. These approaches preserve a single optical core in each fibre while increasing the number of physical fibres that can be accommodated.

These solutions are already available on the market: 200-µm low-coating-thickness fibres are already well established, and 180-µm and even 160-µm diameters are being trialed, while ribbon cables now achieve very high fibre densities while maintaining a compact footprint (but possibly at the expense of long distance transmission performance regarding fibre linear attenuation).

3.2.

Densifying channels within the fibre

The objective is to exploit several transmission paths in one fibre. **The main approaches are multicore fibre (MCF), few-mode fibre (FMF) and combined few-mode multicore fibre (FM-MCF).** These technologies add spatial channels through multiple cores, multiple propagation modes, or both.

Key takeaway

Not all SDM technologies represent the same level of disruption. Some increase the density of conventional fibres, while others create several spatial channels within a single fibre.

A practical technology map

Approach	Representative technologies	What is densified?
More fibres in the same space	RCDF, RCF and high-density ribbon cables	The cable and interface
More channels in each fibre	WC-MCF, RC-MCF, FMF and FM-MCF	The fibre itself

3.3.

SDM is not a single level of technological disruption

Reduced-diameter fibres are evolutionary: they increase physical density while retaining one core per fibre (1).

Multicore fibres introduce several cores within a common cladding, with each core potentially forming a spatial channel (2).

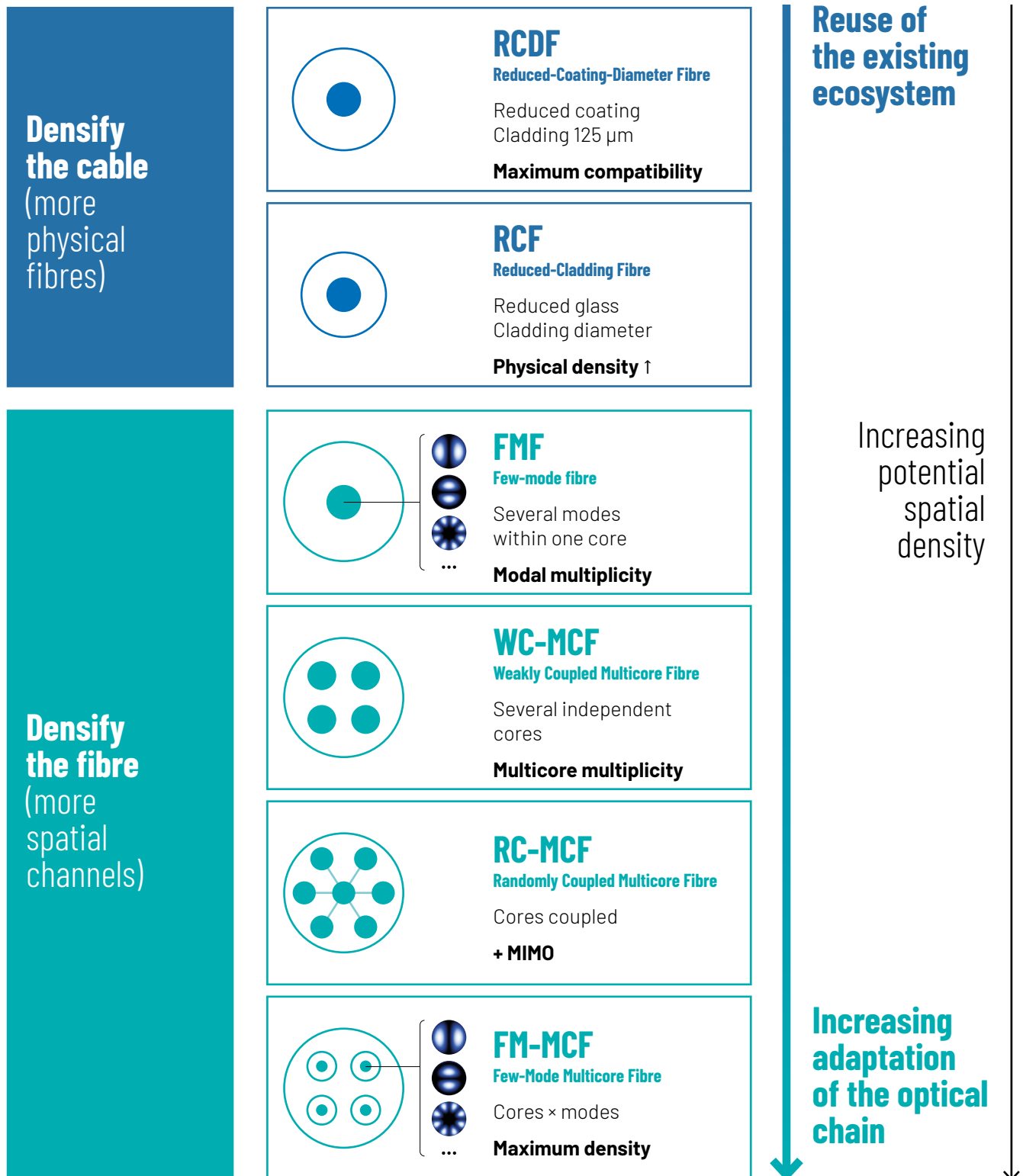
Few-mode fibres use several propagation modes in the same core (3).

Few-mode multicore fibres combine both dimensions, creating higher theoretical spatial multiplicity together with greater system complexity (4).



The SDM fibre families: from cable to fibre

From geometric optimisation of conventional fibres to spatial-channel multiplication.



4. Main SDM fibre families: comparative view

The indicative density factors below are directional comparisons, not direct performance guarantees. Maturity and compatibility vary by application and by the availability of the complete ecosystem.

Technology	Density principle	Indicative density	Maturity	Ecosystem compatibility	Main benefits	Main points of attention
SMF	One fibre, one core, one spatial path	×1 Reference	Very high ●●●●● Widely commercialised	Very high ●●●●●	Complete ecosystem; established splicing, connectivity, test and operations	Densification generally requires more fibres or cables
RCDF	Reduced coating diameter; glass cladding typically remains 125 µm	Around ×2 Design dependent	High ●●●●○ Commercially available	High ●●●●○	Higher fibre count without changing the transmission principle	Greater microbend sensitivity; mechanical protection and handling precautions
RCF	Reduced glass cladding and generally reduced coating diameter	Around ×2 Design dependent	Intermediate ●●●●○ Available for selected applications	Medium ●●●●○	Higher cable and interface density with conventional transmission	Adaptation to 125 µm ecosystem; mechanical reliability and specific connectivity
FMF	Several propagation modes used as spatial channels in one core	×M where M is the number of modes	Low to intermediate ●●●●○ Advanced prototypes and demonstrations	Low to medium ●●●●○	Potentially high multiplicity in a standard-size cladding	Modal multiplexing, intermodal crosstalk, differential delay and frequent MIMO-DSP
WC-MCF	Several sufficiently isolated cores form independent spatial channels	×4 (Typically) Higher counts under development	Intermediate ●●●●○ Early industrialisation	Medium to high ●●●●○	Direct multiplication of channels per fibre; potentially SMF-like cores	Inter-core crosstalk; core orientation; adapted splicing, fan-in/fan-out and connectivity
RC-MCF	Closely spaced, intentionally coupled cores form spatial modes	Above ×10 (Potentially)	Low to intermediate ●●●●○ Advanced prototypes and demonstrations	Low ●●●●○	Very high spatial multiplicity potential	MIMO-DSP required; specific characterisation, connectivity and limited direct SMF compatibility
FM-MCF	Several cores, each supporting several modes	× N × M Where N is number of cores and M number of modes. Highest potential	Low ●●●●○ Research and demonstration	Very low ●●●●○	Multiplication of both cores and propagation modes	High complexity across fibre, cable, fan-in/fan-out, modal multiplexing, test and signal processing

Reading guide: RCDF and RCF densify the cable by integrating more physical fibres. FMF, WC-MCF, RC-MCF and FM-MCF densify the fibre by providing more spatial channels. Every density factor must be considered together with ecosystem maturity and system-level adaptation.

5. Comparing technologies beyond density

A solution should not be selected solely on the basis of an “x2”, “x4” or higher density factor. Industrial relevance depends on the complete system. The following questions provide a practical evaluation framework.

Density

How many additional optical paths are obtained?

Performance

Are attenuation, dispersion and crosstalk controlled for the target transmission system?

Compatibility

Can existing systems, connectors, tools and operating practices be used?

Cabling

Are bare-fibre properties preserved after colouring, buffering, assembly and cabling?

Connectivity

Are angular alignment, fan-in/fan-out or additional components required? Do splice trays or closures need to be modified or changed?

Test and measurement

Are characterisation methods available, repeatable and suitable for field use?

Deployment

Can the solution be installed and operated under real field conditions?

Reliability

Does it withstand mechanical stress, bending and ageing?

Economics

Is the benefit confirmed at complete-system level?

Environment

Does densification reduce resources and impacts over the life cycle?

DECISION PRINCIPLE

The most attractive solution is not necessarily the one with the highest theoretical density. It is the one that delivers the required density with an acceptable level of performance, compatibility, reliability, complexity and cost.

Key takeaway

A higher channel count is only valuable if performance, reliability and deployability can be maintained across the complete optical link.

6. From fibre to cable: where the promise is proven

An SDM fibre cannot be evaluated only in its uncabled state. Its value depends on maintaining performance through colouring, buffering, assembly, cabling, installation and connectivity. Cable-induced mechanical and geometrical constraints can influence optical properties. Macrobending, microbending and twisting may affect attenuation or crosstalk between spatial channels.

For multicore fibres, crosstalk can vary with bending and twist conditions. For fibres with non-standard cladding dimensions, mechanical reliability under tension, bending and ageing must also be carefully evaluated. Cable connectivity solutions such as splice closures and handling procedures may need adaptations. Cable architecture must therefore be matched to the fibre type, deployment environment and target link performance.

ACOME Group's industrial perspective

The challenge is not simply to incorporate an innovative fibre into a cable. It is to design an architecture that preserves optical and mechanical performance under real manufacturing, installation and operating conditions. This interface between optical innovation and deployment reality is where cable engineering creates value.

ACOME Group follows the development of SDM technologies, contributes to collaborative ecosystem work and examines the conditions required to translate new fibre concepts into high-performance, industrialisable and deployable connectivity solutions. The focus extends from preservation of performance after cabling to integration within existing infrastructure.

7. Industrialisation requires an ecosystem

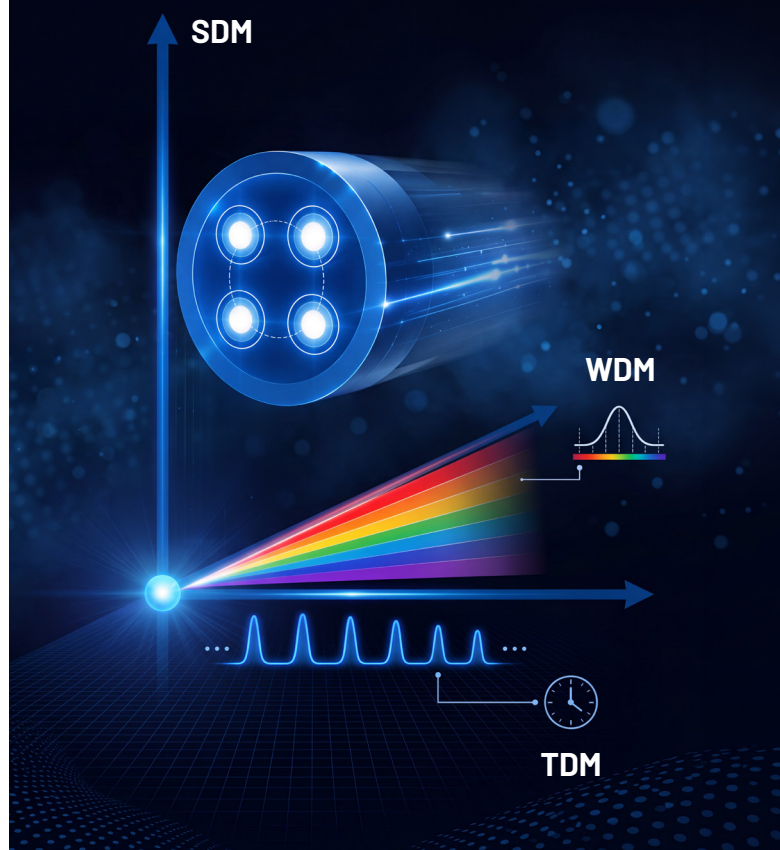
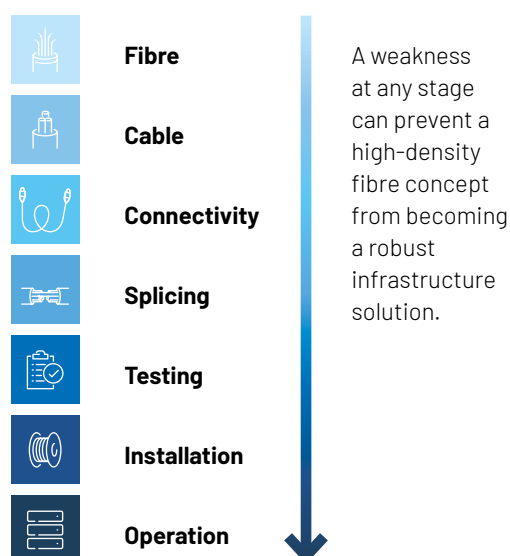
SDM is not limited to fibre and cable. Depending on the selected architecture, a complete link may also require:

- fan-in/fan-out devices;
- mode multiplexers and demultiplexers;
- adapted connectors;
- splicing equipment capable of managing core orientation;
- adapted splice trays and closures
- specific test and measurement methods;
- amplifiers supporting several spatial channels;
- interoperability rules, qualification methods and operating practices.

Maturity therefore depends on more than fibre availability. Some network building blocks can be reused directly, others require adaptation, and some remain to be developed or standardised.

Industrialisation will require coordinated progress across fibre manufacturers, cable designers, component suppliers, equipment vendors, operators, research organisations and standardisation bodies.

From concept to deployed infrastructure



8. What this means for infrastructure stakeholders

Operators

Assess SDM against the dominant bottleneck in each network segment, not against density alone.

Hyperscalers and data-centre owners

Consider link density, interface density, operational simplicity and the readiness of the connectivity ecosystem together.

Equipment and component suppliers

Align interfaces, fan-in/fan-out functions, splicing, measurement and interoperability around target applications.

Industrial manufacturers

Demonstrate repeatable performance after manufacturing, cabling, qualification and installation.

Research and standardisation bodies

Help translate experimental progress into comparable parameters, test methods and interoperable specifications.

Conclusion: from spatial density to deployable infrastructure

The continued growth of cloud, AI, high-performance computing, mobile and data-centre connectivity is increasing both the capacity and the number of optical paths required by networks. In many environments, physical space, interface density and deployment complexity are becoming as important as transmission performance.

Space Division Multiplexing introduces a new dimension for optical-network development. By integrating more fibres into a given space, or by creating multiple spatial channels within a single fibre, SDM can extend the capacity of constrained infrastructures. Its different technology families offer distinct balances between density, compatibility, maturity and system complexity.

The industry's next challenge is therefore not simply to demonstrate higher spatial multiplicity. It is to convert that potential into complete solutions that preserve performance through cabling, connectivity, installation, measurement and long-term operation.

Progress will depend on coordinated work across the ecosystem, including fibre manufacturers, cable designers, component suppliers, equipment vendors, network operators, research organisations and standardisation bodies.

WHY IT MATTERS, WHY NOW, WHAT COMES NEXT

SDM matters because network growth increasingly requires more optical paths within constrained spaces. It matters now because infrastructure density is becoming a system-level limitation. Its future will depend on the industry's ability to move from promising fibre concepts to interoperable, industrialised and deployable solutions.

Glossary

DCI	Data Centre Interconnection
DSP	Digital Signal Processing
FIFO	Fan-In/Fan-Out
FMF	Few-Mode Fibre
FM-MCF	Few-Mode Multicore Fibre
HPC	High-Performance Computing
MCF	Multicore Fibre
MIMO	Multiple-Input Multiple-Output
RCDF	Reduced-Coating-Diameter Fibre
RCF	Reduced-Cladding Fibre
RC-MCF	Randomly Coupled Multicore Fibre
SDM	Space Division Multiplexing
SMF	Single-Mode Fibre
WC-MCF	Weakly Coupled Multicore Fibre
WDM	Wavelength-Division Multiplexing

References

- ITU-T, Technical Report GSTR-SDM (09/2022), "Optical fibre, cable, and components for space division multiplexing transmission", International Telecommunication Union, Geneva, September 2022.
- ITU-T, G Supplement 87 (03/2025), "Standardization framework for optical fibres for space division multiplexing", International Telecommunication Union, Geneva, March 2025.
- SDM4 MCF MSA, "Standardizing 4-Core Multicore Fibre for AI Data Center Interconnects", announced 11 March 2026.
- W. Chen, L. Yuan, B. Zhang et al., "Applications and Development of Multi-Core Optical Fibres", Photonics, vol. 11, no. 3, 270, 2024.
- [ACOME Group, "White Paper G.654.E Fibre & Cable", available at \[acome.com\]\(https://www.acome.com\).](#)



Next in the series

The next white paper will examine multicore fibres in greater depth: their main architectures, including weakly coupled, randomly coupled and few-mode multicore designs; their key design parameters, including core pitch, confinement, attenuation and crosstalk; and the criteria used to match fibre architecture to application requirements.



Kevin Lenglé

ACOME Group

Kévin Lenglé, Ph.D., combines a master's degree in engineering from ENSSAT and a doctorate in physics with a strong background in ICT. His experience spans research at the French National Centre for Scientific Research (CNRS) and product line management within telecom equipment manufacturers.

Since joining ACOME as Marketing Manager in 2021, he leverages his ICT expertise in optics and telecommunications to drive the development and commercialization of sustainable optical cables and connectivity.



52 rue du Montparnasse
75014 Paris - France
T. +33 1 42 79 14 00

www.acome.com