Efficiently adding mode multiplexing for cost-effective, high-capacity fiber links

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For decades, a powerful approach to adding data capacity in an optical communication link has been to multiplex independent data-carrying channels and transmit them simultaneously along a fiber.[1] For example, wavelength-division-multiplexing (WDM) was a key technology in the 1990s and early 2000s to dramatically increase aggregate capacity in a fiber by multiplexing beams of different wavelengths.[2]

For the past roughly 15 years, there has been great promise that space-division-multiplexing (SDM) may bring similar capacity enhancements to optical fiber communications.[1–3] A key subset of SDM is mode-division-multiplexing (MDM), in which multiple data-carrying beams are each transmitted along a fiber, such that each beam propagates with a different spatial mode in a fiber that supports multiple modes. Such modes have a unique phase and amplitude spatial distribution and are orthogonal to each other.[1–5]

Indeed, one can combine WDM and MDM to transmit significantly more data channels and increase capacity (see Fig. 1). Often, a systems designer may not want to stress any single multiplexing domain too much. For example, it may be relatively straightforward and use inexpensive components when a system uses only a few wavelengths, whereas using a large number of wavelengths may be much more demanding and expensive due to stability and crosstalk issues. Indeed, if one wants to increase capacity, a systems designer may find it compelling to increase the number of wavelengths and the number of modes per wavelength, instead of increasing only the number of wavelengths.

One of the key challenges in fiber-based MDM is the power coupling from one mode to another, thus producing deleterious channel crosstalk.[1–5] This channel crosstalk is often mitigated by using powerful electronic digital-signal-processing (DSP) techniques, such as multiple-input-multiple-output (MIMO) channel equalization.[1–5] However, MIMO DSP tends to be fairly complex and consumes relatively large amounts of power.[5]

Can one add modes per wavelength in a straightforward and cost-effective manner? Jian Wang and his team recently and impressively addressed this issue, in their article, "Finding the superior mode basis for mode-division multiplexing: a comparison of spatial modes in air-core fiber" (doi 10.1117/1.AP.5.5.056003). Importantly, the paper by Wang et al. clearly and impressively demonstrates that by choosing an appropriate modal basis set, one can reduce inter-modal power coupling in an air-core fiber (ACF) and enable a MIMO-free communication system.

Their work provides the theoretical underpinnings and experimental verification for the modal power coupling in an ACF when considering various types of modes. The paper shows convincingly that circularly-

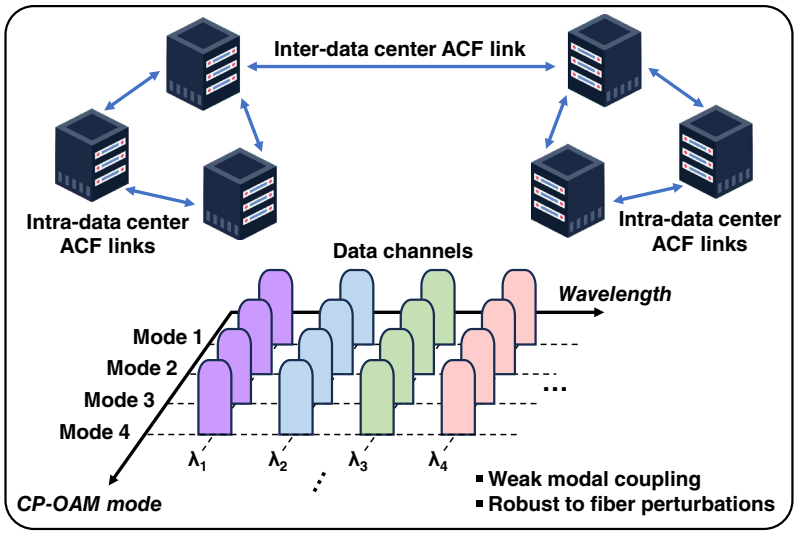

Fig. 1 The paper by Wang et al. provides valuable insights on how to efficiently add mode multiplexing for cost-effective and high-capacity fiber links. One potentially impactful application could be in significantly increasing the data capacity of future intra- and inter-data center links by adding mode multiplexing using CP-OAM modes in ACFs, which is compatible with WDM.

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polarized orbital-angular-momentum (CP-OAM) modes have lower crosstalk when compared to three other types of modes, specifically linearly polarized modes, linearly-polarized OAM modes, and vector modes; we note that OAM modes can be considered a subset of Laguerre Gaussian modes.[6,7] Importantly, the paper by Wang et al. shows a 1-km MIMO-free MDM communications link using an ACF that considers the real-world effects of fiber perturbations (e.g., bending, twisting, pressing, winding, moving, and various environmental disturbances) on crosstalk, thus justifying their important results.

One potentially impactful application of their results could be in significantly and cost-effectively increasing the data capacity of future intra- and inter-data center links (see Fig. 1). Such links tend to be highly cost- and power-sensitive, and the ability to transmit a few wavelengths each with a few spatial modes over an ACF with no MIMO signal processing might have significant value. This value could apply to both direct-detection and coherent-detection links, as well as those with higher-order modulation formats – as was shown by Wang et al.

As fiber communication systems continue to advance, it is highly likely that the insights contained in the paper by Wang et al. will play an important role in cost-effective and power-efficient capacity enhancements.

References

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