ICT TODAY

THE OFFICIAL TRADE JOURNAL OF BICSI

January/February/March 2020
Volume 41, Number 1

BICSI®

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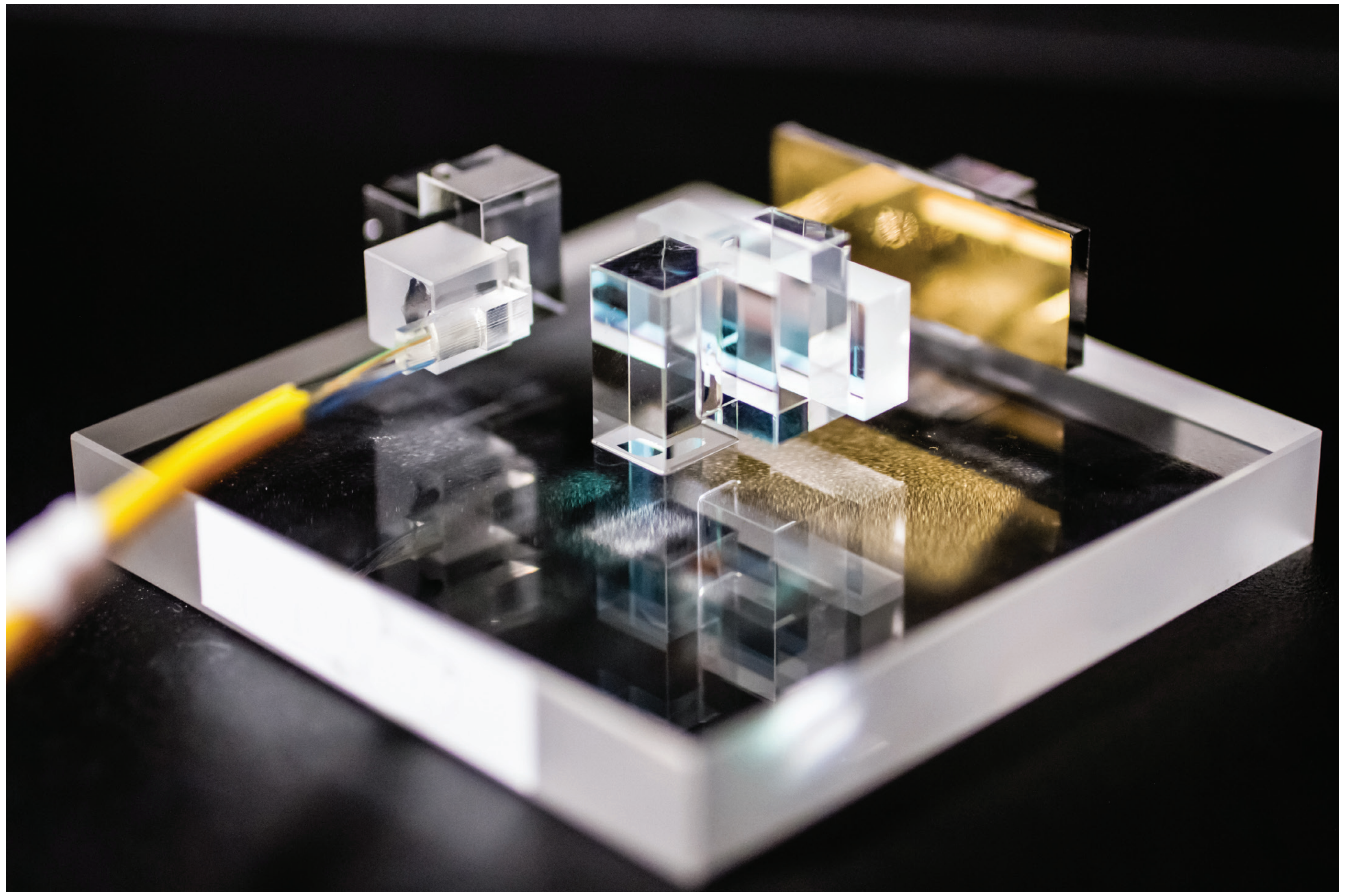

Discover How to Convert Multimode Optical Fibers into Singlemode to Support Growing Bandwidth Demands

By Kevin Lengle, Ph.D.

Digital communications within local networks are undergoing rapid expansion and occupying an increasingly important role. This evolution in communication modes has a direct influence on supporting infrastructures. In order to support this expansion and any congestion issues that may arise, networks need to be more efficient.

In response, an innovative technology based on multi-plane light conversion (MPLC) overcomes the bandwidth limitation of multimode fibers, which constitute the backbone of many LANs. To understand MPLC fully, it is important to understand the current fiber landscape, the intricacies of multimode optical fiber, and how the technology has been used at the Georgia Institute of Technology (Georgia Tech) campus for its OM1 (62.5/125 μm) upgrade.

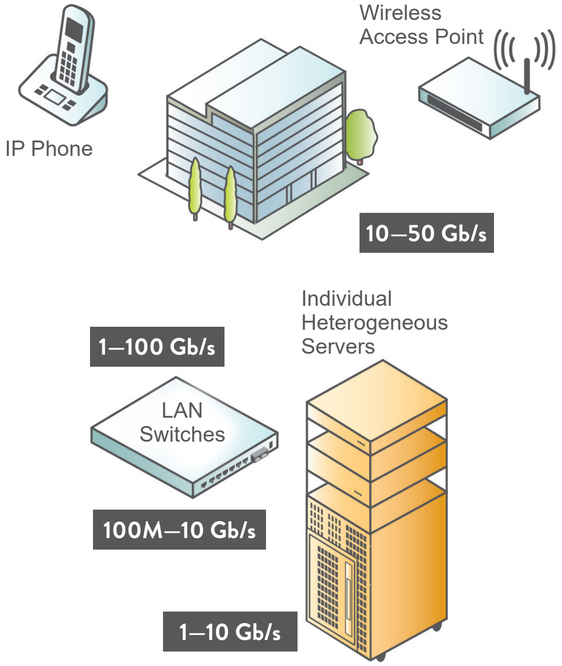

FIGURE 1: The growing demand for increased bandwidth in LANs.

A GROWING DEMAND FOR INCREASED BANDWIDTH IN LOCAL NETWORKS

Over the past several years, a lot of effort has been put into the development of optical transmission systems at 10 Gb/s in LANs. A growing number of applications require high bandwidth in order to ensure ongoing transfer and streaming of large volumes of data, audio files and videos. In addition, the multiplication of mobile terminals and online devices has contributed to the need for higher bandwidth. Therefore, bandwidth-intensive applications and latency-aware traffic types are becoming ubiquitous in the LAN. As a result, it is necessary to be able to transport these data streams with a high quality of service (QoS) and reliability. Nearly 75 percent of the optical fibers deployed in the LAN are multimode fibers. A large majority of deployed multimode optical fibers do not support throughput of 10 Gb/s over campus-wide links. This is largely due to the design of this fiber which was optimized for lower throughputs. Contrary to the active components of the network, for which upgrades can be carried out relatively easily through a software or hardware upgrade, the optical fiber cabling infrastructure has a performance envelope that previously could not be increased without physically changing the cable that carries the information.

THE ISSUE OF MODAL DISPERSION IN MULTIMODE OPTICAL FIBERS

Optical fiber is widely used to carry information due primarily to its small size, low linear losses, and insensitivity to electromagnetic disturbances. However, optical fiber possesses intrinsic performance limitations which are inherent to its physical properties. For multimode optical fibers installed in the 1980s and 90s, such as OM1 (62.5/125 μm) and OM2 (50/125 μm), high-speed transmission is limited as a result of modal dispersion. Modal dispersion is a distortion mechanism occurring in multimode fibers. Due to the different velocities of the modes, the signal is spread out and often deformed over time during the propagation in the fiber as shown in Figure 2.

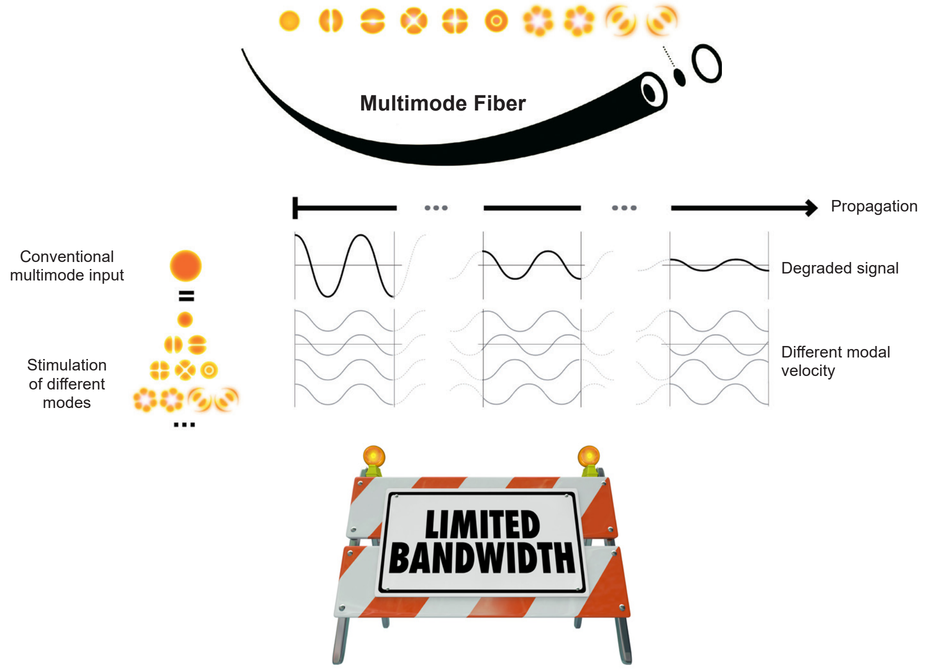

FIGURE 2: Modal dispersion affects all multimode fiber types, thereby degrading the bandwidth capacity of the multimode optical fiber.

Maximum distance of link	100 Mb/s (100BASE-FX)	1 Gb/ (1000BASE-SX)	10 Gb/s (10GBASE-SR)	40 Gb/s (40GBASE-SR4)
OM1 (62.5/125)	2000 m	400 m	33 m	N/A
OM2 (50/125)	2000 m	550 m	82 m	N/A
OM3 (50/125)	2000 m	575 m	315 m	100 m
OM4/OM5 (50/125)	2000 m	600 m	500 m	150 m

TABLE 1: Performance of multimode optical fibers: throughput versus distance.

This leads to inter-symbol interference and the inability to retrieve the data that was transmitted. The higher the transmitted throughput, the greater the distortion. All multimode fibers are affected by modal dispersion, including OM5. Certain optical fiber properties, especially the refractive index profile of the fiber, strongly impact the velocity of the different modes of propagation, thereby causing modal dispersion. As glass transformation techniques have evolved over the years, there are different generations of graded-index multimode fibers (OMx, x = 1, 2, 3, 4 or 5) that decrease the differential mode delay between modes according to the fiber type and, therefore, the impact of modal dispersion on bandwidth. To sum up, modal dispersion degrades the width of the bandwidth capacity of the multimode optical fiber. For a given throughput, it reduces the distance that can be reliably attained between the transmitter and receiver. As a result, standard transmission over multimode fiber within 850 nm operating wavelength with 10GBASE-SR is limited to distances of up to 33 meters (36 yards) on conventional 62.5 µm OM1 fibers and 82 meters (90 yards) over conventional 50 µm OM2 fibers. Table 1 provides an overview of the performances of multimode optical fibers types.

A typical solution that prevents throughput and distance limitations due to modal dispersion in legacy multimode fiber cabling is to upgrade to a newer-generation multimode fiber type or to singlemode optical fiber, which does not experience modal dispersion. However, redeploying the fiber cabling is frequently a difficult task. It depends upon the distances involved and the difficulties in drawing the fibers. An audit of the cabling infrastructure is necessary in order to verify the availability of the cable duct as well as its condition. Depending on the case, civil engineering may be required to deploy new cable sheaths. For these reasons, the complexity and costs of redeploying new cable can be exorbitant. Following this approach may result in a complex installation with a significant impact on the business and its budget.

SPECIFIC LIGHT LAUNCHING CONDITIONS TO OVERCOME OPTICAL MULTIMODE FIBER BANDWIDTH LIMITATIONS

The problem of multimode fiber transmission capacity as it relates to the need to increase the throughput was discussed as far back as the late 1990s. To try and overcome the multimode bandwidth limitation, a new type of 10 Gb/s interface was introduced within the IEEE 802.3aq standard, referred to as long reach multimode (LRM). These interfaces are specifically designed for backward compatibility with OM1 and OM2 fibers. The LRM interfaces transmit within the range of 1300 nm and are capable of the same transmission distance over OM1 and OM2 fibers, up to 220 meters (240 yards). The key to the longer reach of the 10GBASE–LRM standard on conventional multimode fibers is the use of a sophisticated signal processing technology in the receiver portion of these devices. The specialized signal processing is referred to as electronic dispersion compensation (EDC). EDC is deployed as an integrated circuit that acts as a complex continuous adaptive filter on the received signal from the optical fiber in order to reduce inter-symbol interference.

FIGURE 3: The problem of multimode fiber transmission capacity has led to the creation of technologies that upgrade existing cabling infrastructure.

To achieve the maximum distances of 220 meters at 10GB/s, 10GBASE-LRM transceivers must be used with mode conditioning patch cables (MCPCs) at both ends of the fiber link. The standard relies on specific launch conditions. The mode conditioning patch cord is a special assembly that precisely offsets the singlemode fiber centerline with the multimode fiber centerline. This configuration is referred to as the *offset launch* technique. Therefore, mode conditioning patch cord partially controls the light launch location of the singlemode fiber from the LRM source into the multimode fiber. More precisely, this type of patch cable produces a launch that only excites some of the modes within the multimode fiber optical core, mainly higher order modes.

By reducing the number of modes excited by this offset launching technique, the impact of modal dispersion is reduced in terms of differential mode delay and inter-symbol interference, thereby allowing the maximum distance over multimode optical fiber to be increased at a high throughput. While mode conditioning patch cables reduce the number of excited modes and improve the odds of finding a favorable operating condition, they also provide diversity in the modes it excites; there is no fiber or connector specification that ensures a minimum bandwidth level for this launch condition. Thus, depending on the quality of the optical cable and the eccentricity of field connectors, it is a hit-or-miss situation, leaving users to experiment on-site with their own optical fibers. Furthermore, the maximum distance of 220 meters, supported by 10GBASE-LRM equipment, is unfortunately often too short for LAN backbone cabling networks for which typical lengths equal or exceed 300 meters (330 yards). Cabling surveys that list the needs for distance capabilities of existing 10 Gb/s multimode solutions indicate that supporting only 220 meters addresses only 60 percent of multimode links in local networks.

> *All multimode fiber types are affected by modal dispersion.*

Many studies have been carried out within the IEEE 802.3aq workgroups, and one of them focused on the launching offset range needed to maximize bandwidth increase. Theoretical results showed a significant gain in bandwidth within a range of 15-to-20 µm offset launch. This range is what is being targeted today in the manufacturing of MCPCs. However, this offset range corresponds to a secondary maximum for the bandwidth gain. The maximum gain is obtained for a zero offset. Such a technique is called *center launching*. The best-case scenario would be to perform mode conditioning, thereby enabling a launching condition that accurately excites the fundamental center mode into the multimode fiber core. In this way, the light transmission within the multimode fiber would no longer induce modal dispersion as only one mode would propagate; this can be considered a kind of quasi-singlemode transmission over the multimode fiber. By reducing the number of modes excited by this center launching technique to one, the impact of modal dispersion moves towards zero in terms of differential mode delay and inter-symbol interference, thereby allowing the maximum distance over multimode fibers to be increased at a high throughput.

A MORE EFFICIENT INNOVATIVE MODAL ADAPTING PASSIVE TECHNIQUE

One way to overcome modal dispersion is to carry the information in just one mode over multimode fibers. By properly exciting a single fiber spatial mode, the coupling of the signal to different group modes and propagation speeds is negligible. Consequently, the spatial mode can then be used as an independent high-speed transmission channel with the same transmission properties as singlemode fiber. Essentially, MPLC enables flexible and

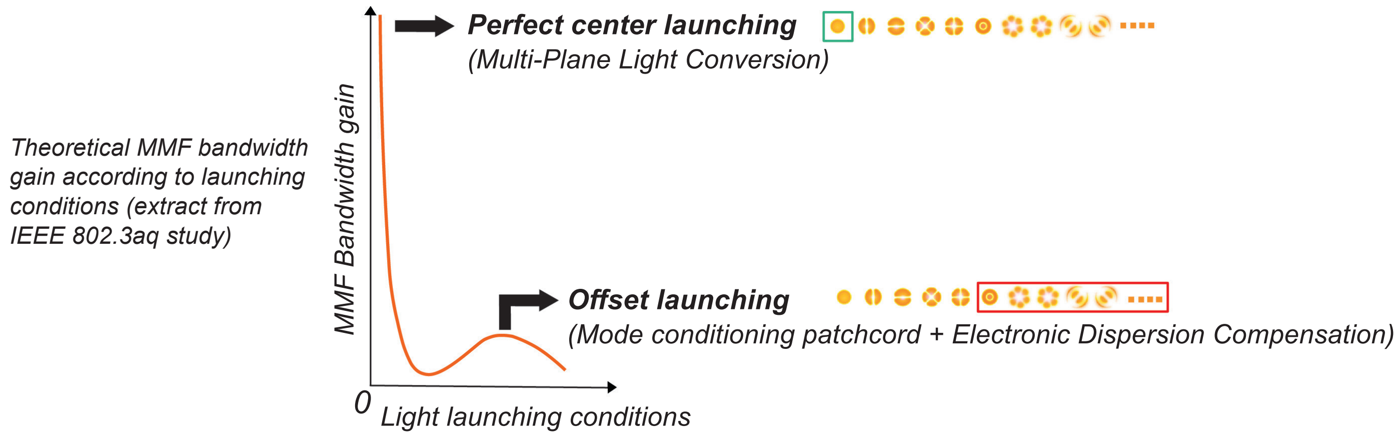

FIGURE 4: Multimode Fiber (MMF) bandwidth gain comparison between perfect center launching (MPLC) and offset launching.

complete light shaping with very little loss through a succession of transverse phase profiles similar to very complex optical lenses. The technology shapes a laser beam (light from a transceiver) in such a way that each mode within the multimode optical fiber can be independently and precisely excited. Today, MPLC technology is used to increase the transmission capacity and to achieve bandwidth gains of existing multimode fibers by performing perfect center launching on legacy multimode fibers (Figure 4). By overcoming speed and distance limitations, up to 100 Gb/s can be carried over an existing multimode infrastructure up to several kilometers. There are solutions adapted to different topologies that allow for a progressive and flexible evolution of the legacy network optical infrastructure, compatible with any 62.5/125 µm or 50/125 µm multimode fiber types (i.e., OM1 to OM5).

Because this technology consists solely of optical elements, the solutions are passive (e.g., no energy consumption, no supervision) and operate at the physical layer level, which makes them transparent to the communication protocol and modulation format used. There is no need for EDC or complex digital processing at the reception of the transmission; simple detection systems, such as direct detection, are sufficient. This technique is transparent to wavelength and can operate in the O-band (1300 nm window) or C-band (1500 nm window) range with standard singlemode transceivers at 1 Gb/s, 10 Gb/s or even higher. Intrinsic loss of such a modal adapter is less than 2 dB and does not add transmission power penalty. Considering the linear losses of optical fibers at these high wavelengths and the sensitivity of singlemode standard transceivers, the overall optical budget of the link remains sufficient to transmit information over long distances and to cover the requirements for all types of LANs that need their legacy multimode fiber cabling infrastructure upgraded.

CASE STUDY: UPGRADING THE CONNECTIVITY OF FRATERNITY HOUSES AT GEORGIA TECH

The Georgia Institute of Technology, also known as Georgia Tech, is a public research university located in Atlanta, Georgia. This university strives to provide high-speed connection to fraternity houses on campus in order to provide students with high quality services, such as robust Wi-Fi coverage with increased wireless access points (WAPs); high quality wired internet access in the face of increased data traffic in the era of bring your own devices (BYOD); and increased digital content to support online student learning that improves the students' experience via innovative teaching tool platforms, TV/video services, and campus social networking.

> *MPLC enables flexible and complete light shaping with very little loss through a succession of transverse phase profiles similar to very complex optical lenses.*

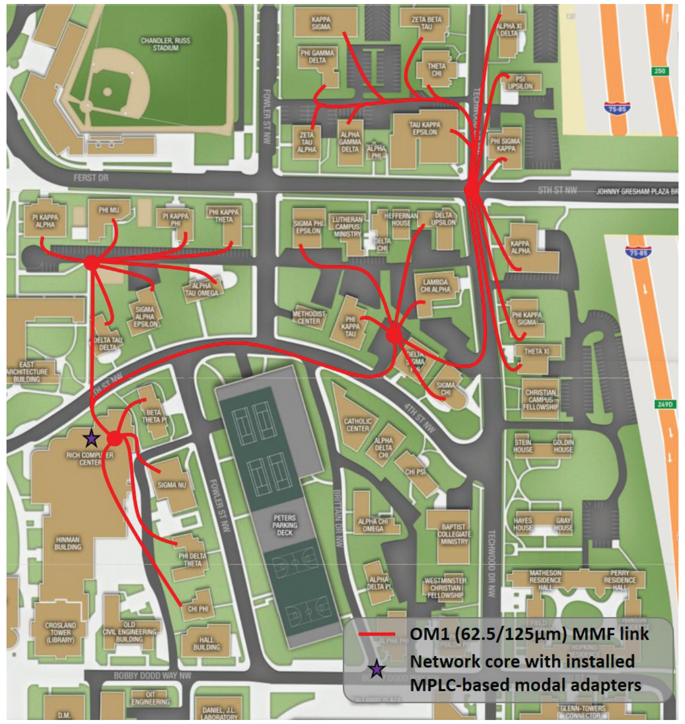

FIGURE 5: Georgia Tech campus illustration showing multimode fiber links and the network core with installed MPLC-based modal adapters.[1]

On campus, more than 30 fraternity buildings are connected to the core network by OM1 multimode fibers that were deployed many years ago. The demand for increased throughput involved 38 multimode optical links. These multimode fibers, ranging in length from 400 to 1,100 meters (1,310 to 3,610 feet), were unable to transmit information at the required rate of 10 Gb/s.

Recabling can be complex. Most of the cable ducts were no longer available and the operational constraints were too great to implement the project. Recabling would have been a very costly solution to this problem. The network managers of this university, being intently focused on technological innovation, were attracted to the MPLC technology shown at the 2018 BICSI Winter Conference and Exhibition in Orlando, Florida. Georgia Tech ultimately adopted MPLC technology to meet its broadband requirements using its existing multimode links (Figure 5). The center launching modal adapters were installed and implemented as shown in Figure 6.

For lengths under 800 meters (875 yards), the center launching modal adapter was installed at just one end of the optical fiber pair to the network core. The equipment was spliced to existing multimode fiber undergoing the upgrade. Since the multimode connectors have eccentricity tolerances of a few micrometers, it was

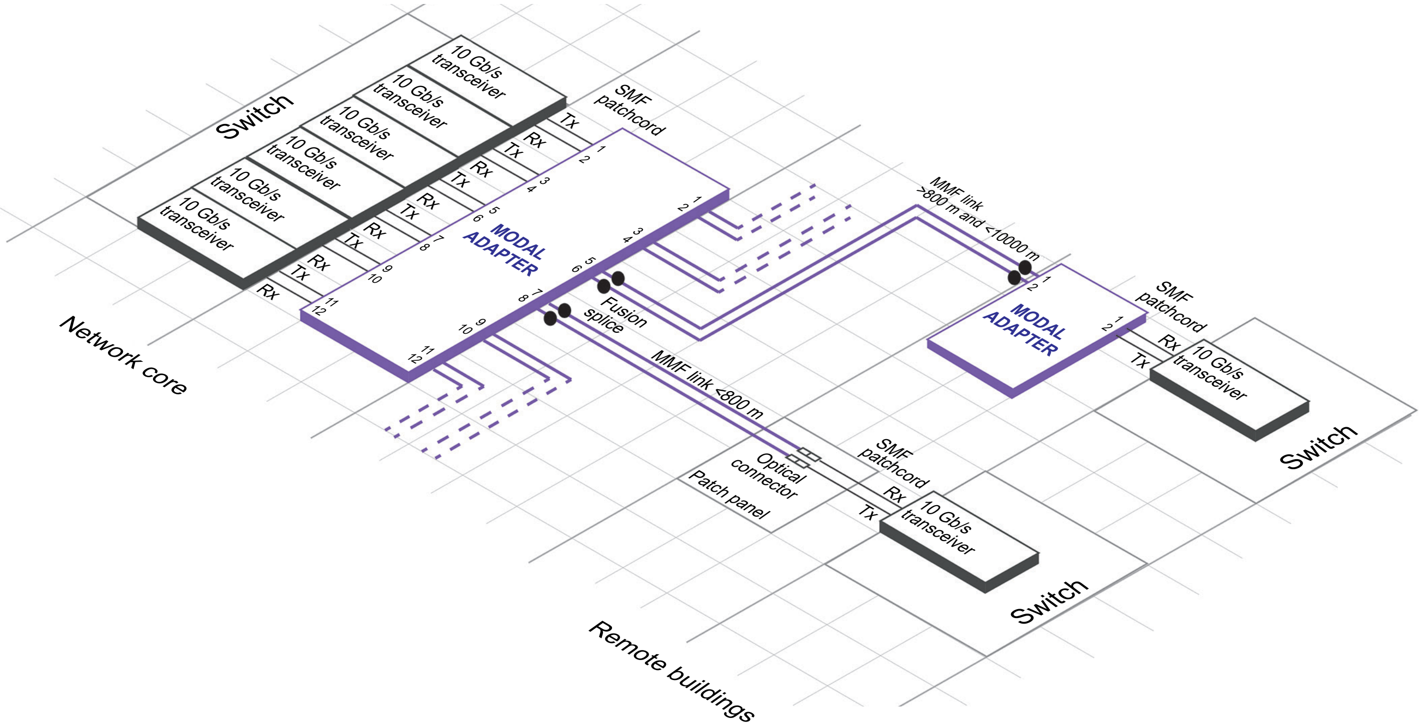

FIGURE 6: Georgia Tech's MPLC-based modal adapter implementation scheme.[2]

FIGURE 7: Georgia Tech's MPLC-based modal adapter in small form factor or in standard 19" 1RU racks.[3]

recommended that the equipment be spliced to the existing multimode fibers to ensure that the modal alignment between the cores of the optical fibers were efficient. It should be noted that this type of technology does not require specific equipment or the installation of a splicing program. Modal adapting equipment, provided in standard 1RU 19'' rack, then became the new patch panel for the upgraded multimode fibers. On the remote site, no modal adapting equipment was needed. The patch panel that the multimode fibers connect to was preserved. The patch cords that connected the distribution panel and the active equipment were simply replaced by standard singlemode patch cord, since the transmission over the multimode fiber was now approaching the features and characteristics of singlemode fiber. The transceivers usually use LC type connectors. Therefore, singlemode LC/ST or LC/SC cords or any other necessary connector type can be employed depending on the project's specific multimode connectivity.

Upon transmission, the modal adapter served as a perfect center launcher while acting as a perfect mode filter on the receiver, retaining only the information transmitted on the fundamental mode. For a link longer than 800 meters, a modal adapter was required at both ends of the fiber link to ensure optimal mode conditioning.

As shown in Figure 7, Georgia Tech's 1RU racks contained the different modal adapters installed in the bay with all the multimode fiber panels that were upgraded. Note that there were also modal adapters in the form of compact modules which could upgrade a single pair of multimode fibers. This type of module must be simply spliced to the existing multimode optical fibers and inserted into the existing distribution drawer, which helps to conserve space in network bays that are often already very full.

Compared to recabling, this project was less complex for the installer; it required less time and had fewer cost constraints for the end customer. "All buildings with OM1 multimode fibers are up and running well on 10Gb/s network speeds," says Robert Toledano, Engineer III at Georgia Tech, who was in charge of the upgrade project for the multimode infrastructure. He adds, "This was a significantly less complex and expensive option; the project costs of using MPLC technology plus labor costs were approximately 75 percent less than the associated costs of recabling."

> *MPLC-based technology is used to increase the transmission capacity and to achieve bandwidth gains of existing multimode fibers by performing perfect center launching on legacy multimode fibers.*

NEW HORIZONS FOR ICT PROFESSIONALS AND END USERS

The MPLC-based controlled mode launching technology has also been tested and validated by many in the ICT industry at speeds of 40 Gb/s and 100 Gb/s on long legacy OM1 and OM2 multimode fiber links. It also makes multimode optical fibers compatible with singlemode wavelength division multiplexing (WDM) technologies, thereby enabling a gradual and flexible increase in network capacity toward very high-speed broadband while ensuring a durable cabling infrastructure.

In addition to traditional LAN Ethernet architectures, new perspectives are emerging for the passive optical LAN (POL), which aims to be a sustainable LAN implementation that offers capacity and security to the workstation through GPON technology at lower operational and energy costs while saving space. These architectures were initially designed on a singlemode optical cabling infrastructure for greenfield projects, but MPLC-based technology now makes them compatible with existing multimode optical fibers. This paves a way to facilitate the adoption of POL in existing networks for brownfield projects.

In view of current and future needs, the limited capacity of cabling infrastructure is a prevalent issue. Moreover, complex cabling cases are not uncommon. This MPLC-based modal adapting technology has already proven its effectiveness across numerous industrial, military, university and hospital campuses. The decrease of operational and economic constraints for end customers makes it possible for ICT professionals to close business faster by showing them an efficient alternative. It also facilitates the realization of projects that had previously been blocked for these reasons. The competitive advantage conferred to professionals offering this advanced technology allows them to differentiate themselves and attract new customers. In addition, a network upgrade facilitated with fewer human resources enables professionals offering this MPLC innovation to achieve better margins. As a complement to traditional cabling, it also makes it possible to secure all contracts by adding this technology to tenders.

To sum up, there is now an innovative technology that allows enterprises to preserve their existing multimode fiber cabling infrastructure. Thus, this positive disruptive technology offers a new alternative to solving the issues of ever-increasing bandwidth needs and rising throughputs in LANs—along with proven benefits for both end customers and ICT professionals.

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REFERENCES:

1. Figure 5 ©2019 Georgia Institute of Technology. All rights reserved.
2. Ibid
3. Ibid