ICT TODAY

THE OFFICIAL TRADE JOURNAL OF BICSI

November/December 2018
Volume 39, Number 6

Evolution of Cabling Infrastructure Design and IoT Compatibility

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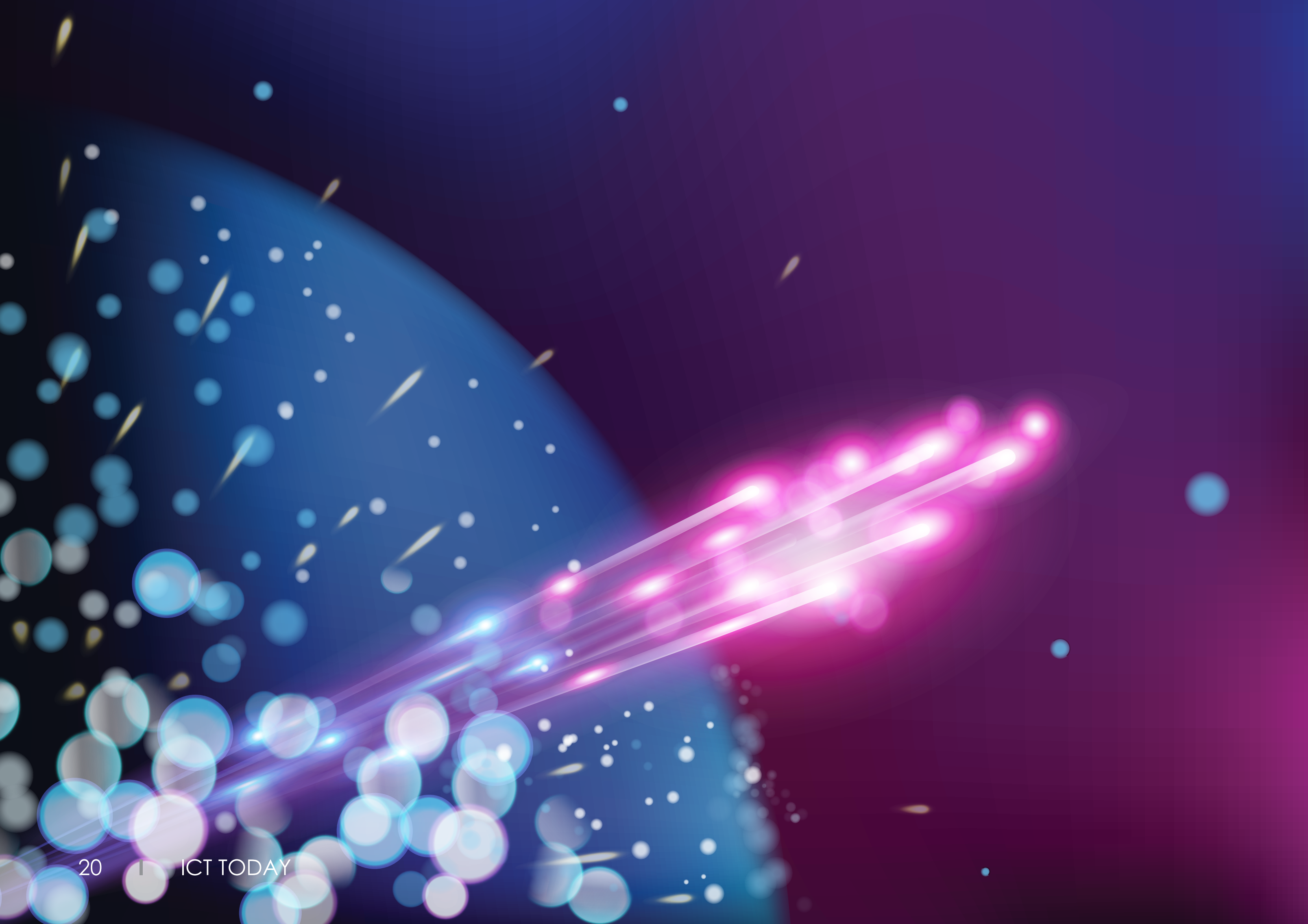
Enterprise Fiber Standards and Applications: What's New?

By John Kamino, RCDD

In enterprise and data center networks, cloud computing and web services continue to drive increased bandwidth demand, pushing data communications rates from 1 and 10 Gigabits per second (Gb/s) to 40 and 100 Gb/s and beyond. Multimode optical fiber easily supports most distances required for these applications and continues to evolve to meet greater demand for speed and capacity. This article outlines the latest developments in multimode fiber types and technology available for this market space and the standards that govern them.



Multimode Market Continues to Boom

According to the 2017 Cisco Visual Networking Index, the amount of IP traffic is growing at an annual rate of 24 percent worldwide. The 2018 Cisco Global Cloud Index shows that global data center traffic is expected to increase from 6.8 zettabytes (ZB) in 2016 to 20.6 ZB in 2021. While the most significant growth is expected in the Asia Pacific region, every segment of the globe shows significant growth. This demand drives the need for higher speed networks, and consequently higher optical fiber volume in all regions.

Among Cisco's other findings: there is almost five times more traffic inside the data center than from the data center to the user. When combined with data center interconnect traffic, this so-called "east-west traffic" accounts for more than 85 percent of total traffic. This helps to explain the demand for higher data center network speeds and more links between servers and switches.

It is a truism that the enterprise data center is moving to the cloud. But what exactly does that mean? An obvious answer is that some enterprises are migrating to public cloud services offered by hyperscale vendors, such as Google, Microsoft, Amazon and others, but there are other approaches. An enterprise private cloud can provision service for its users in similar fashion to one of the hyperscale providers, but with owned rather than leased facilities. A combination of the two approaches can also be used. Cisco projects that the enterprise cloud, now the majority of the market, will continue to grow throughout the study period, reflecting a migration from legacy enterprise data centers, and in some cases, a pull back to in-house control from hyperscale providers. The public cloud will grow at an even faster pace, while the legacy enterprise data center will decrease.

It is sometimes taken as fact that hyperscale data center customers only want singlemode fiber. However, Google, Alibaba and Baidu, for example, have deployed multimode fiber applications and continue to plan for its use in their roadmaps. The market is also seeing an increasing interest in multimode applications from other hyperscale players in the United States for 400G-SR4.2 (a standard to be discussed later) and 400G-SR8 for a variety of applications, including breakout.

Given the distance advantages offered by singlemode fiber, why is multimode fiber still a preferred media? The reasons have to do with cable size, design and cost.

How Multimode Fiber Stacks Up

Until about 2010, copper had been used for data center server links. However, as server speeds increased, the link distance supported by copper twinaxial cable (twinax) and UTP Category5/6 cables significantly decreased, in some cases to as short as five to seven meters (m). For 40 Gb/s links, an 8-pair twinax cable is often used. However, a twinax cable is three or four times the diameter of a fiber cable (Figure 1). When large numbers of these cables are used, it significantly affects airflow around the rack, making it much more difficult to cool. By comparison, optical fiber cables, with their much smaller diameter, demand far less cable management space and are easier to manage.

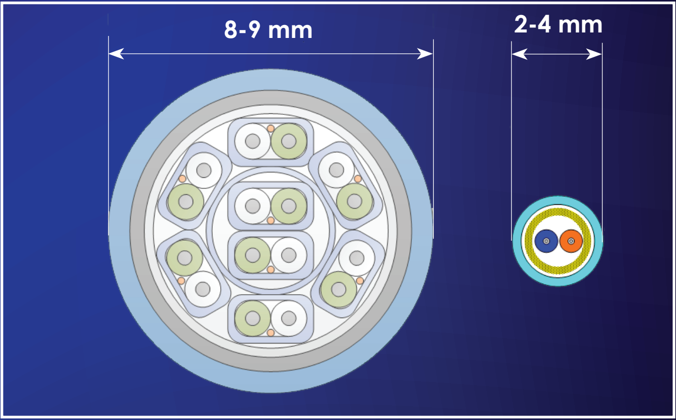


FIGURE 1: Size difference between copper twinax (8 pair) and duplex fiber solutions for 40 Gb/s.

Among optical fiber types, multimode continues to be more cost-effective than singlemode for these shorter reach applications. While the cost of multimode fiber is greater than that of singlemode, it is the optics and connection costs that dominate the total cost of a network system, dwarfing variations in cable costs.[1]

On average, singlemode transceivers continue to cost from one-and-a-half to five times more than multimode transceivers, depending on data rate. As faster optoelectronic technology matures and volumes increase, prices come down for both, and the cost gap between multimode and singlemode can decrease. However, singlemode optics have traditionally been more expensive than their equivalent multimode counterparts.[2]

Multimode fiber is the default choice of transmission media for data centers and other high-speed enterprise applications over copper and singlemode fiber. The reasons have to do with cable size, design and cost.

Multimode transceivers also consume less power than singlemode transceivers, an important consideration especially when assessing the cost of powering and cooling a data center. In a large data center with thousands of links, a multimode solution can provide substantial cost savings from transceiver and power/cooling perspectives. Finally, the fact that multimode optical fiber is easier to install and terminate in the field than singlemode is an important consideration for enterprise environments where frequent moves, adds and changes are required. This advantage extends to cleaning, where a small amount of dust or contamination could create significant attenuation on a singlemode connector, but only slightly increase the loss of a multimode link.

The Evolution of Multimode Fiber

As shown in Table 1, there are five types of multimode fiber currently on the market.

OM1 and OM2, the original 62.5 micron (µm) and 50 µm-diameter types, respectively, are considered obsolete in the ISO/IEC 11801 and TIA 568 standards, and no longer included in the main text of the documents. They are, however, allowed as grandfathered fiber types and may be used to extend legacy networks. New installations should use OM3, OM4 or OM5 multimode fiber types.

OM3 multimode, introduced in 2003, was the first fiber designed for use with laser light sources at 850 nanometers (nm), primarily to support 1 and 10 Gb/s operation. OM4, standardized in 2009, offers longer link lengths supporting 10 Gb/s operation to 400 m in the standard, and up to 550 m using some engineering rules.

	*(described in the industry using primarily the **ISO/IEC 11801** Designations)*							**BANDWIDTH** (MHz-km)			
	Industry Standards					**Attenuation—** Typical Cabled Max. (dB/km)		**Overfilled Launch (OFLc)**		**Effective Modal Bandwith (EMB)** (also known as Laser BW)	
Fiber Type	**ISO/IEC 11801-1 Nov. 2017**	**IEC 60793-2-10 Aug. 2017**	**TIA-568.3-D Oct. 2016**	**TIA/EIA 492AAAx various**	**ITU-T Dec. 2008**	**850nm**	**1300nm**	**850nm**	**1300nm**	**850nm**	**953nm**
62.5/125	~~OM1(1)~~	A1b	~~TIA 492AAAA (OM1)~~	492AAAA	---	3.5	1.5	200	500	---	---
50/125	~~OM2(2)~~	A1a.1b(3)	~~TIA 492AAAB (OM2)~~	492AAAB	G.651.1	3.5	1.5	500	500	---	---
50/125	OM3	A1a.2b(3)	TIA 492AAAC (OM3)	492AAAC	---	3.0(4)	1.5	1500	500	2000	---
50/125	OM4	A1a.3b(3)	TIA 492AAAD (OM4)	492AAAD	---	3.0(4)	1.5	3500	500	4700	---
50/125	OM5	A1a.4b(3)	TIA 492AAAE (OM5)	492AAAE	---	3.0	1.5	3500	500	4700	2470

(1) OM1 is typically a 62.5µm fiber, but can also be a 50µm fiber.
(2) OM2 is typically a 50µm fiber, but can also be a 62.5µm fiber.
(3) "b" designates Bend-Insensitive
(4) ISO/IEC 11801 has a max. cabled attenuation of 3.5dB/km

TABLE 1: Multimode fiber types.

An even more recent innovation was the introduction in 2017 of OM5, known as wideband multimode fiber. Traditionally, multimode fiber has operated at a single wavelength. When higher network speeds were needed, lasers were developed that would operate at these speeds. This approach worked very well up to 10 Gb/s and, later, 25 Gb/s. To increase speeds further, however, parallel fiber systems were introduced; first for 40 Gb/s, then for 100 Gb/s. Four fibers, or lanes, were used to support these higher speed links.

OM5 fiber is the first multimode fiber designed to support multiple wavelengths. It enables duplex transmission of 100 Gb/s using either two or four wavelengths between 850 and 950 nm. This is done while taking advantage of multimode fiber's longer wavelength transmission properties. The fiber's lower chromatic dispersion at longer wavelengths means that modal bandwidth requirements could be relaxed at those longer wavelengths.

Commercial transceivers are available to support either technology. In fact, several large transceiver manufacturers were key contributors to the wideband multimode fiber standard. They provided guidance on the wavelength spacing needed for the most cost-effective wavelength division multiplexing (WDM). This resulted in a transmission window that went from the current 850 nm up to 953 nm.

Other than some limited application in service provider central offices, 100GBASE-SR10 has been less widely deployed, in large part because newer standards requiring fewer fiber pairs have been developed.

An additional requirement was the support of all existing OM4 applications and reaches. In other words, OM5 fiber is completely backward compatible with all OM4 requirements and supports applications to the same link distances.

Table 2 indicates where the OM5 specifications were tightened in order to support WDM applications. Notice that the 850 nm laser bandwidth (also called effective modal bandwidth, or EMB) remains the same at 4700 Megahertz over one kilometer (MHZ-km). Transmission reach at 850 nm matches all OM4 applications. The additional bandwidth requirement is at 953 nm, the long or "far" end of the wavelength range, where a laser bandwidth of 2470 MHz-km is specified. The window between these two wavelengths is the space designed for multimode WDM applications.

	OM4 Multimode Fiber	OM5 (Wideband) Multimode Fiber
Zero Dispersion Wavelength	$1295 \leq \lambda_o \leq 1340$ nm	$1297 < \lambda_o < 1328$ nm
Zero Dispersion Slope	$S_0 \leq 0.105$ ps/nm^2·km for $1295 \leq \lambda_o \leq 1310$ nm, and $\leq 0.000375(1590-\lambda_o)$ ps/nm^2·km for $1310 \leq \lambda_o \leq 1340$ nm	$S_0 \leq 4(-103)/(840(1-(\lambda_o/840)^4))$ ps/nm^2·km
850 nm Effective Modal Bandwidth (EMB)	4700 MHz-km	4700 MHz-km
953 EMB	N/A	2470 MHz-km

TABLE 2: Specification comparison between OM4 and OM5 wideband multimode fiber.

OM5 multimode fiber and cable standards are fully mature and complete. TIA completed fiber standard TIA-492AAAE in June 2016, and IEC published IEC 60793-2-10 in August 2017. TIA published its structured cabling standard, ANSI/TIA-568.3-D, in October 2016, and ISO/IEC published ISO/IEC 11801-1 in October 2017. The 11801 standard defines the OM5 designation for multimode wideband fiber. That designation will also be included, with reference to 11801, in future TIA and IEC fiber standards.

Equipment Trends Follow Suit

What equipment can be used with OM5 multimode fiber? Table 3 shows currently available short wavelength division multiplexing (SWDM) transceivers, along with one announced solution. It is clear that, while OM3 and OM4 still support short-reach applications, OM5 gives added reach to the full range of applications.

The first widely deployed application for OM5 fiber was 40 Gb/s bidirectional (BiDi) transceivers. Duplex (BiDi and SWDM4) 40 Gb/s links are widely deployed; as 100 Gb/s solutions become more commonplace, similar trends can be expected in that space. The introduction of an extended-reach SWDM (eSWDM4) solution will further expand the market for multimode fiber with its ability to support 400-m duplex 100 Gb/s links.

To encourage these developments, an SWDM alliance was formed in 2015. This industry-based organization, which includes OFS and other optical fiber and cable suppliers as well as transceiver and switching equipment suppliers, was created to promote the use of SWDM technology for short-reach applications. An SWDM multi-source agreement (MSA) has also been created to develop interoperable SWDM devices. Specifications for both 40 Gb/s and 100 Gb/s transceivers were released and are available on the swdm.org website.

Recently, a 400 Gb/s BiDi MSA was announced. This MSA will continue to build on the advantages of multi-wavelength solutions with a four-pair 400 Gb/s link. The goals of this MSA include the development of a specification that will support up links up to 150 m over OM5 fiber.

It should be pointed out that these are not standards-based solutions; they are either MSA-based or proprietary offerings from switch and/or transceiver suppliers. However, the transceivers do fit into the standard quad small form-factor pluggable (QSFP+ or QSFP28) footprint, and as long as they are paired with a like transceiver, no problems should be encountered.

While these applications can operate over legacy OM3 and OM4 fiber, OM5 fiber offers a significant reach advantage over the older fiber types.

New Developments in Multimode Signal Transmission

Another technical achievement not tied specifically to wideband transmission is the use of four-level pulse amplitude modulation (PAM-4) signaling, which is a more complex signaling method than the simple

				Link Distance (m)		
Speed (Gb/s)	Transceiver	Form Factor	λ	OM3	OM4	OM5
40	BiDi	QSFP+	2	100	150	200
40	SWDM4	QSFP+	4	240	350	440
100	BiDi	QSFP28	2	70	100	150
100	SWDM4	QSFP28	4	75	100	150
100	eSWDM4	QSFP28	4	200	300	400

TABLE 3: LC Duplex SWDM transceivers (non-standards based).

The second PMD is 400GBASE4.2. This will be the first standards-based application that will exhibit the reach advantage of wideband OM5 fiber.

on-off keying (OOK) previously used in optical transmission. Instead of simply transmitting a 1 or 0, PAM-4 transmission doubles the amount of information that can be sent in a single time period by using four signal levels. PAM-4 signaling will be incorporated into new Ethernet and Fibre Channel standards, as well as MSAs and proprietary solutions as speeds increase. It will allow for 50 Gb/s per lane transmission using today's 25 Gbaud/s lasers, and as laser speeds increase further, will allow even higher lane speeds.

Of course, nothing is free. PAM-4 signaling will require better receiver sensitivity than OOK in order to detect the different levels. As seen in Figure 2, four "eyes" will need to be detected, rather than the single eye found in OOK. The sensitivity requirements can be reduced using several compensation methods, including equalization and/or forward error correction.

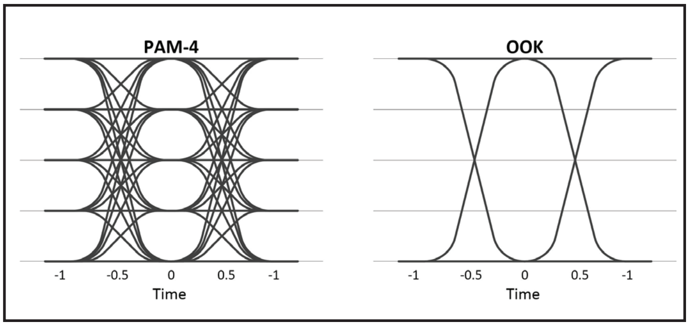


FIGURE 2: Comparison of OOK sensitivity to PAM-4.

Latest Ethernet Standards

The first Ethernet standards for 40 Gb/s (40GBASE-SR4) and 100 Gb/s (100GBASE-SR10) were adopted in 2010. Both used parallel fibers to support higher bit rates on short reach (SR) links (the "4" or "10" following the "SR" designates the number of fiber pairs in the link). Each fiber pair carried 10 Gb/s bi-directionally, so four pairs were needed to support 40 Gb/s and 10 pairs were used to support 100 Gb/s. Typically, a 12-fiber multi-fiber push on (MPO) connector was used as the interface for 40 Gb/s, while a 24-fiber MPO connector was used for 100 Gb/s (two 12-fiber MPOs could also be used).

40GBASE-SR4 has been widely deployed. Initially very popular for server breakout applications where one 40 Gb/s switch port was used to support four 10 Gb/s servers, native 40 Gb/s switch-to-switch links quickly followed. 40GBASE-eSR4 modules are also available to support longer distance links. While not defined in the standard, transceiver manufacturers are increasingly developing "beyond the standards" products that can support longer link distances found in some data centers.

Other than some limited application in service provider central offices, 100GBASE-SR10 has been less widely deployed, in large part because newer standards requiring fewer fiber pairs have been developed.

Both PMDs support up to 150 m link lengths on OM4, but as noted previously, 40 Gb/s transceivers are available that can support longer links.

Soon after its introduction, it became obvious that 100GBASE-SR4 could be used in breakout situations similar to early 40 Gb/s installations, and a single-pair 25GBASE-SR standard was written in 2016. The application space is similar to that for 40 Gb/s breakout, with four 25 Gb/s servers supported by a single 100GBASE-SR4 switch port.

Additional 200 and 400 Gb/s Ethernet solutions were introduced in 2017. Here, only one multimode PMD was included. 400GBASE-SR16 uses 16 fiber pairs, each transmitting at 25 Gb/s. This PMD is not expected to be widely deployed as there is reluctance on the part of end users to deploy 32 fiber cables to support a single link. Newer multimode Ethernet standards being developed will use fewer fiber pairs by incorporating PAM-4 technology and WDM.

What's Ahead for Ethernet?

Table 4 highlights Ethernet standards under development for multimode fiber. IEEE802.3cd is working on a 50/100/200 Gb/s standard, which is expected to be published in the second half of 2018.

PMD	Link Distance	Fiber Count (f) and Media Type	Technology	
50GBASE-SR	100 m OM4/OM5	2-f multimode	1x50G PAM-4 850 nm	**Active – Publication expected in 2018**
50GBASE-FR	2 km	2-f singlemode	1x50G PAM-4 1300 nm	
50GBASE-LR	10 km	2-f singlemode	1x50G PAM-4 1300 nm	
100GBASE-SR2	100 km	4-f multimode	2x50G PAM-4 850 nm	
100GBASE-DR	500 km	2-f singlemode	1x100G PAM-4 1300 nm	
200GBASE-SR4	100 km	8-f multimode	4x50G parallel PAM-4 850 nm	

TABLE 4: Standards under development for 50/100/200 Gb/s Ethernet (IEEE 802.3cd).

The multimode standards are all based on 50GBASE-SR, a 50 Gb/s PAM-4 lane that can support up to 100 m on both OM4 and OM5 fiber. Since the 802.3cd PMDs operate only at 850 nm, there is no advantage to the multi-wavelength support offered by OM5 fiber. 100GBASE-SR2 is a two-pair solution, while 200G BASE-SR4 is a four-pair solution for 200 Gb/s.

The latest IEEE task force to be formed is IEEE 802.3cm. This group has approval to develop two new 400 Gb/s multimode standards. The first PMD, 400GBASE-SR8, will use eight pairs of multimode fiber, each pair carrying 50 Gb/s. This was driven by a hyperscale customer who wanted the flexibility this solution offered, including breakout of 50, 100, and 200 Gb/s, as well as 400 Gb/s switch-to-switch links. There will be two different media interfaces for 400GBASE-SR8: the new 16-fiber MPO that was recently standardized in TIA and the older 24-fiber MPO connector that has two rows of 12 fibers.

The second PMD is 400GBASE4.2. This will be the first standards-based application that will exhibit the reach advantage of wideband OM5 fiber. The task force has established several important parameters, including that the second wavelength (910 nm) and transmission will be bi-directional (BiDi). 400GBASE-SR4.2 plans to introduce a new naming scheme to clearly define the lanes used in the PMD: SRx.y, in which "x" indicates the number of fibers and "y" is the number of wavelengths.

Conclusion

Bandwidth demands in all parts of the enterprise continue to grow and application speeds are increasing to support those needs. Enterprise cloud, hybrid and hyperscale data centers will continue to deploy multimode optical fiber links, and multimode transceivers are evolving to support higher speed links needed in the newest data centers, including the hyperscale market.

Multimode links continue to have cost and operational advantages over competing media types. Through the standards organizations and groups, such as the SWDM Multi-Source Agreement, the industry continues to develop new technological solutions to meet this explosive market demand.

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