Cabling Installation & Maintenance

EXECUTIVE SUMMARY

Fiber-Optic Connectivity Best Practices from 100G to 800G

John Kamino, Senior Manager – Multimode Optical Fiber Product Management, OFS
Ken Hall, RCDD NTS, Data Center Solutions Architect, Cloud, HyperScale Solutions, CommScope

NOVEMBER 4, 2021

KEY TAKEAWAYS

- VCSEL-based multimode links are still relevant for today's high-speed networks.
- Today's communications networks utilize multimode and singlemode optical fiber.
- As cloud data centers migrate to 100 Gb servers, new approaches to switching and cabling are emerging.
- Multimode deployment will focus on short-reach data center applications and singlemode deployment will be used for longer data center links.
- Cloud infrastructure and services are driving the need for new data center network topologies.
- QSFP-DD and OSFP modules are the best way to fully utilize switch capacity.
- Looking ahead, support for 800G capacity and co-packaged optics is a possibility.
- Now is the time to prepare for 400G and above, since network architecture design looks different at higher speeds.

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Fiber-Optic Connectivity Best Practices from 100G to 800G

OVERVIEW

The growth of cloud infrastructures and cloud services is driving the need for faster networks. As data centers migrate to 100 Gb servers, IT teams are taking new approaches to switching and cabling. Multimode optical fiber is well suited for short-reach data center applications, while singlemode is ideal for longer links. Devices like QSFP-DD and OSFP modules enable network designers to fully utilize switch capacity and prepare for network speeds of 400G and above. To develop efficient and flexible data center designs that will stand the test of time, network and infrastructure teams must collaborate and align their objectives.

CONTEXT

John Kamino discussed multimode and singlemode fiber for speeds 100G and beyond, as well as the latest high-speed networking standards, multi-source agreements (MSAs), and proprietary solutions. Ken Hall explored how updated data center architectures and building blocks can deliver improved performance and efficiency.

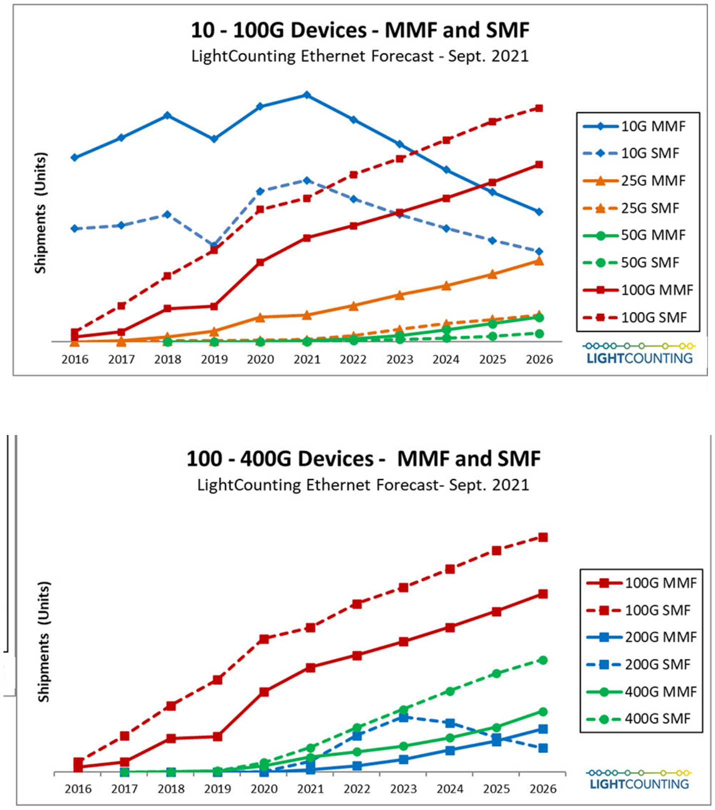
KEY TAKEAWAYS

VCSEL-based multimode links are still relevant for today's high-speed networks.

The big push for silicon photonics started around 2010 and 2011. Many industry experts predicted that multimode and VCSEL-based (vertical cavity surface emitting laser) electronics wouldn't compete with silicon photonics.

Fast forward to today, and silicon photonics-based products account for less than 20% of all optical transceiver sales. They haven't overwhelmed the alternative technologies or killed multimode and VCSEL-based electronics.

Figure 1: Multimode Transceiver Shipment Growth



Today's communications networks utilize multimode and singlemode optical fiber.

Multimode optical fiber has a larger, 50-micron core, while singlemode has a smaller, eight-micron core. Both have a clad diameter of approximately 125 microns. Other distinctions include:

- Multimode operates at a lower wavelength range, between 850 and 940 nm. Some legacy multimode 1300 nm applications also exist. The tolerances for aligning optical devices to multimode cores are much looser than for single mode. This is because light can take different paths down the core of multimode optical fiber. In an ideal multimode fiber, light modes arrive at the far end of the fiber at the same time. The larger cores and lower wavelengths associated with multimode optical fiber drive source and system costs

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down. OM1 and OM2 multimode types are no longer recommended for greenfield applications, although they are still used in many legacy applications.

- Singlemode optical fiber operates primarily between 1310 nm and 1625 nm. The small core in singlemode guides only one mode. This eliminates modal dispersion and enables tremendous transmission capacity over very long distances.

OS1a fiber is used primarily for inside plant applications and OS2 is used for outside plant applications. The difference between these fiber types is the attenuation. OS1a has a one dB per kilometer attenuation at 1310 nm, 1385 nm, and 1550 nm. OS2 has a 0.4 dB per kilometer attenuation at those three wavelengths.

Figure 2: Standard Multimode Types

*(described in the industry using primarily the **ISO/IEC 11801** designations)*

Fiber Type	Industry Standards					Attenuation - Typical Cabled Max. (dB/km)		Bandwidth (MHz-km): Overfilled Launch (OMBc)		Bandwidth (MHz-km): Effective Modal Bandwidth (EMB) (also known as Laser BW)	
	ISO/IEC 11801-1 Nov. 2017	IEC 60793-2-10 May 2019	TIA-568.3 2021 draft	TIA/EIA 492AAAF April 2020	ITU-T Dec. 2008	850nm	1300nm	850nm	1300nm	850nm	953nm
62.5/125	~~OM1~~	A1-OM1	~~TIA 492AAAF (A1-OM1)~~	A1-OM1	---	3.5	1.5	200	500	---	---
50/125	~~OM2~~	A1-OM2	~~TIA 492AAAF (A1-OM2)~~	A1-OM2	G.651.1	3.5	1.5	500	500	---	---
50/125	OM3	A1-OM3	TIA 492AAAF (A1-OM3)	A1-OM3	---	3.0(2)	1.5	1500	500	2000	---
50/125	OM4	A1-OM4	TIA 492AAAF (A1-OM4)	A1-OM4	---	3.0(2)	1.5	3500	500	4700	---
50/125	OM5	A1-OM5	TIA 492AAAF (A1-OM5)	A1-OM5	---	3.0	1.5	3500	500	4700	2470

(2) ISO/IEC 11801 has a max. cabled attenuation of 3.5dB/km

ISO/IEC 11801-1	"Generic Cabling for Customer Premises"
IEC 60793-2-10	"Optical fibres - Part 2-10: Product specifications - Sectional specification for category A1 multimode fibres"
TIA-568.3-D	"Optical Fiber Cabling and Components Standard"
TIA/EIA-492AAAF	"Detail Specification for Class 1a Graded- Index Multimode Optical Fibers; Modification of IEC 60793-2-10:2019"
ITU-T G.651.1	"Characteristics of a 50/125 um Multimode Graded Index Optical Fibre Cable for the Optical Access Network"

Acronyms

ISO	International Organization for Standardization
IEC	International Electrotechnical Commission
TIA	Telecommunications Industry Association (North American)
EIA	Electronic Industries Alliance (North American)
ITU	International Telecommunications Union

Figure 3: Ethernet Multimode Modules – Speed >= 100Gb/s

Data Rate Gb/s	Ethernet Standard Proprietary/MSA Module	IEEE Standard/MSA/ Proprietary	Adoption/ Introduction	# fiber pairs	# λ's	Optical Modulation	Reach (m): OM3	Reach (m): OM4	Reach (m): OM5
100	100GBASE-SR4	IEEE 802.3bm	2015	4	1	25G NRZ	70	100	Same as OM4
100	100G – SWDM4	MSA	2017	1	4	25G NRZ	75	100	150
100	100G – BiDi	Proprietary	2017	1	2	50G PAM4	70	100	150
100	100GBASE-SR2	IEEE 802.3cd	2018	2	1	50G PAM4	70	100	Same as OM4
100	100GBASE-VR	IEEE P802.3db Task Force	2022	1	1	100G PAM4	30	50	Same as OM4
100	100GBASE-SR					100G PAM4	60	100	
200	200GBASE-SR4	IEEE 802.3cd	2018	4	1	50G PAM4	70	100	Same as OM4
200	200GBASE-VR2	IEEE P802.3db Task Force	2022	2	1	100G PAM4	30	50	Same as OM4
200	200GBASE-SR2					100G PAM4	60	100	
400	400GBASE-SR8	IEEE 802.3cm	2020	8	1	50G PAM4	70	100	Same as OM4
400	400GBASE-SR4.2			4	2		70	100	150
400	400GBASE-VR4	IEEE P802.3db Task Force	2022	4	1	100G PAM4	30	50	Same as OM4
400	400GBASE-SR4			4			60	100	
800	800GBASE-VR8	B400G Study Group	2025?	8	1	100G PAM4	30?	50	Same as OM4
800	800GBASE-SR8						60?	100	Same as OM4
4/800/1600	4/800/1600GBASE-SRm.n(?)	Future Technology		1/2/4/8	TBD	100G PAM4	100m over MMF		

≤ 30-50m breakout to server will be first use of 100G/lane VCSELs

100 Gb/s VCSELs expected in 2021/2022 – will initially support short-reach server interconnects

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Figure 4: Standard Singlemode Types

Fiber Type (TIA definition)	Industry Standards					Attenuation Typical Cabled Max. (dB/km)		
	ISO/IEC 11801 November 2017	IEC 60793-2-50	ANSI/TIA 568.3 2021 Draft	ANSI/TIA 492CAAC April 2020	ITU-T	1310 nm	1385 nm	1550 nm
~~Std SM~~	~~OS1~~	~~B1.1~~		~~492CAAC~~	~~G.652.A or B~~	~~1.0~~	~~N.A.~~	~~1.0~~
SM (ISP)	OS1a		B-652.D or B-657 (OS1a)			1.0	1.0	1.0
SM (Indoor-Outdoor)		B.652.D or B.657	B-652.D or B-657	B.652.D or B.657	G.652.D or G.657	0.5	0.5	0.5
SM (OSP)	OS2[(1)]		B-652.D or B-657 (OS2)			0.4	0.4	0.4

[(1)] *OS2 is referenced in the standard* **ISO/IEC 24702** *"Generic Cabling for Industrial Premises"*

IEC 60793-2-50	"Product Specifications - Sectional Specification for Class B Single-Mode Fibres"
TIA/EIA-492CAAC	"SectionalSpecification for Class B Single-Mode Optical Fibers"
ITU-T G.652	"Characteristics of a single-mode optical fibre and cable"
ITU-T G.653	"Characteristics of a dispersion-shifted single-mode optical fibre and cable"
ITU-T G.654	"Characteristics of a cut-off shifted single-mode optical fibre and cable"
ITU-T G.655	"Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable"
ITU-T G.656	"Characteristics of a fibre and cable with non-zero dispersion for wideband optical transport"
ITU-T G.657	"Characteristics of a Bending Loss Insensitive Single Mode Optical Fibre and Cable for the Access Network"
TIA/EIA-492EA00	"Blank Detail Specification for Class IVd Non-Zero Dispersion Single-

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Figure 5: Ethernet Singlemode Modules – Speed >= 100Gb/s

Data Rate Gb/s	Ethernet Standard Proprietary/MSA Module	IEEE Standard/MSA/ Proprietary	Adoption/ Introduction	# fiber pairs	# λ's	Optical Modulation	Reach (m)
100	100G - PSM4	MSA	2014	4	1	25G NRZ	500
100	100G - CWDM4	MSA	2014	1	4	25G NRZ	2,000
100	100GBASE-LR4	IEEE 802.3ba	2010	1	4	25G NRZ	10,000
200	200GBASE-DR4			4	1	50G PAM4	500
200	200GBASE-FR4	IEEE 802.3bs	2017	1	4	50G PAM4	2,000
200	200GBASE-LR4			1	4		10,000
400	400GBASE-FR8			1	8	50G PAM4	2,000
400	400GBASE-LR8	IEEE 802.3bs	2017	1	8		10,000
400	400GBASE-DR4			4	1	100G PAM4	500
800	**800GBASE-DR8(?)**			**8**	**1**	**100G PAM4**	**500/2,000**
800	**800GBASE-DR4(?)**	**B400G Study Group**	**2025**	**4**	**1**		**500/2,000**
800	**800GBASE-FR4(?)**			**1**	**4**	**200G PAM4**	**2,000**
1600	**1600GBASE-DR8(?)**			**8**	**1**		**500/2,000**

Fiber-Optic Connectivity Best Practices from 100G to 800G

As cloud data centers migrate to 100 Gb servers, new approaches to switching and cabling are emerging.

Many traditional cloud data centers include high-speed modules. In these environments, top-of-rack switches typically support servers in the rack. Those are linked to leaf switches located hierarchically above the top of rack switch. In many cases, the links between the leaf and top of rack switch are singlemode. Links between the top of rack switch and the servers are either copper direct attach cables (DACs) or active optical cables (AOCs).

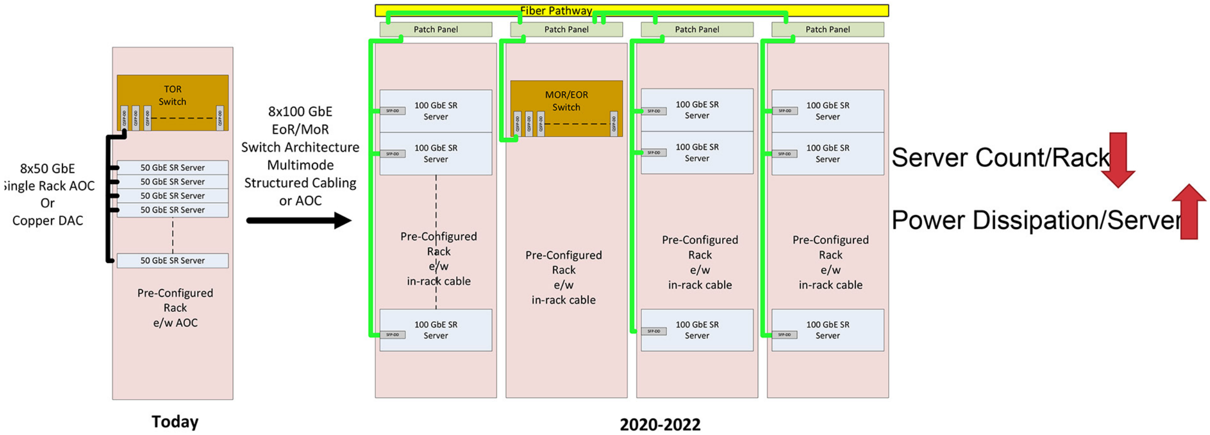
Since enterprise clouds usually operate at lower speeds than hyperscale and the link distances are much shorter, multimode deployments are more common than singlemode. In addition, for the server to top-of-rack switch, copper DACs are used more often than AOCs.

As cloud data centers migrate to 100 Gb servers, network designers often move switches from the top-of-rack location to a middle of row or end of row. Servers are installed in dedicated server racks and these racks are pre-cabled to a patch panel at the top, so they can be rolled in and bolted down. Once the racks are in place, cables are run between patch panels. Since power consumption is significantly higher with 100 Gb servers, the number of servers per rack is limited so adequate power can be supplied for heat dissipation.

Industry experts predict that cost-effective VCSEL optics over 20- to 30-meter multimode fiber will replace copper DACs or AOCs. At the Optical Fiber Communication (OFC) conference in June 2021, Broadcom announced that they have designed 100G kits to support 100G multimode transceivers. These are expected to be in production by early 2022. As outlined in Figure 7, a number of multimode fiber links are under development based on 100 Gb/s PAM4 VCSELs.

Within the next five years, industry experts expect next-generation multimode lane speeds of 200 Gb/s with 100 Gb/s modulation and PAM4 encoding.

Figure 6: The Evolution of Cloud Data Center Architectures



Cost-effective VCSEL optics over 20-30m MMF will replace copper DAC cables or AOCs

Fiber-Optic Connectivity Best Practices from 100G to 800G

Figure 7: Potential MMF Links Based on 100 Gb/s PAM4 VCSELs

- The possible PMDs for 100 Gb/s PAM4 VCSELs are:
  - Single Wavelength Solutions
    - 100GBASE-VR/SR (SFP112)
    - 200GBASE-VR2/SR2
    - 400GBASE-VR4/SR4 (QSFP56-DD) - with breakout to 4×100GBASE-VR/SR
    - 800G-VR8/SR8 - When 800G MAC rate is standardized in the future.
  - Multi-wavelength Solutions
    - 200G-SR1.2, 400G-SR2.2, 800G-SR4.2, and 1.6T-SR8.2
      - Two-wavelength BiDi transmission
    - 400G-SR1.4, 800G-SR2.4, 1.6T-SR4.4 :
      - Four-wavelength SWDM4 technology
- While only some of the above PMDs will have adequate support/need to become either an IEEE 802.3 standard or MSA , 100 Gb/s PAM4 VCSELs lay the foundation for VCSEL-MMF links supporting 800G and 1.6T MAC rates as those rates become standardized in the future.

Multimode deployment will focus on short-reach data center applications and singlemode deployment will be used for longer data center links.

Multimode deployment is well suited for high-speed, short-reach data center applications. Growth is expected in edge data centers, multi-tenant data centers (MTDCs), and enterprise data centers. Fiber-to-the-server hyperscale applications will drive significant market growth for multimode links. In addition, multi-wavelength multimode development will continue.

Singlemode deployment is ideal for longer high-speed data center links. Singlemode will play a significant role in switch-to-switch hyperscale links due to support for longer distances.

> Multimode deployment is well suited for high-speed, short-reach data applications, while singlemode deployment is ideal for longer high-speed data center links.
>
> *John Kamino, OFS*

Cloud infrastructure and services are driving the need for new data center network topologies.

The top five cloud providers in the US, as well as those in China, consume nearly half of the world's cloud-based services. Widespread adoption of cloud-based infrastructures has been accompanied by a shift to higher-speed applications. These trends are influencing network design, data center architectures, and data center cabling decisions.

In response, data center network topologies are evolving. Historically, data centers have used multi-tiered networks. To obtain information or application access, traffic moves up and down in a north-south fashion across different layers of switches to the server. That takes time, power, and money. In addition, top-of-rack switches tend to be a single point of failure.

Today, data center designers are shifting to leaf-spine networks where spine switches are connected to various leaf switches. This provides greater redundancy and mitigates risk. With fewer layers to hop, transaction speeds increase. In addition, east-west traffic supports higher-speed applications between devices.

Leaf-spine networks leverage middle of row or end of row configurations where spine switches are connected to leaf switches. Rather than eight top-of-rack switches in a cabinet row, for example, the data center may have two leaf switches that fully support all the same servers with redundancy. This reduces power consumption and improves network latency. The leaf-spine architecture provides flexibility for newer applications that require 400 Gb/s, 800 Gb/s, or more.

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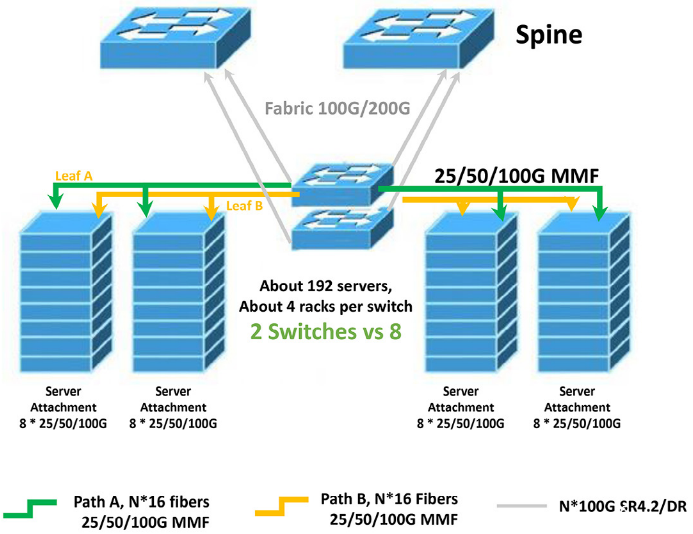
Figure 8: Evolving Data Center Architectures

Figure 9: Middle of Row/End of Row Configuration of a Leaf-Spine Network



QSFP-DD and OSFP modules are the best way to fully utilize switch capacity.

Quad small form pluggable (QSFP) devices typically use eight fibers—four lanes for transmitting data and four lanes for receiving it. QSFP modules have been used for applications such as 40Gb/s or 100 Gb/s. Today, with 400Gb/s and higher data rates, octals (eight lanes each) are needed for transmitting and receiving data at 50Gb/s per lane, with 100Gb/s lanes soon enabling 800Gb/s. This requires quad small form pluggable double density (QSFP-DD) or octal small form pluggable (OSFP) modules.

These transceivers enable data center operators to fully utilize a switch's capacity. This is a much more efficient approach than partially loading or over-sub-scribing the switches. Switch capacity is available on demand. QSFP-DD and OSFP devices are available in multimode and singlemode options to support the distance and application requirements.

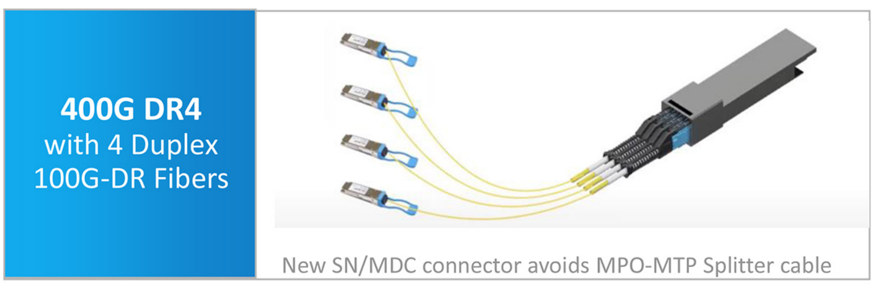
Fiber-Optic Connectivity Best Practices from 100G to 800G

Although the faceplates of 1RU switches are limited to a maximum of 32 QSFP-DD or OSFP ports, new switches have been developed to support faster data speeds. The bandwidth of the switch increases with the number of lanes and the actual data rates per lane.

Figure 10: New 1RU Switch Options Exist

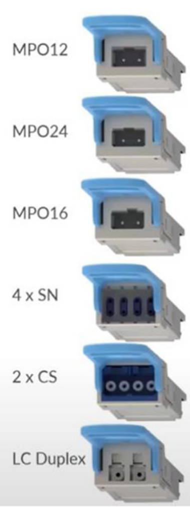
First Deployed	Electrical I/O [Gb/lane]	Switching Bandwidth	TOR/Leaf Data Center Switch Configuration	
~2010	10G	1.28T	32xQSFP+ (40G)	Legacy technology
~2015	25G	3.2T	32xQSFP28 (100G)	128 Electrical I/Os
~2019	25G	6.4T	32 ports of 200G	256 Electrical I/Os
2021	50G	12.8T	32 ports of 400G	
2021	100G	25.6T	32 ports of 800G	512 Electrical I/Os coming soon?

Figure 11: 400G Capacity QSFP-DD Transceivers and Connector options



400G Capacity QSFP-DD – Connectors

Reach	Name Scheme A	Scheme B	Scheme C	Connector
SR (50-70m)	QDD-400G-SR4.2 QDD-400G-SR8 QDD-400G-SR4	400G-BiDi 400G-SR8 400G-SR4		MPO12 MPO16/MPO24 MPO12
DR (500m)	QDD-2x200G-DR4 QDD-400G-DR4	400G-DR8 400G-DR4		MPO16/MPO24 MPO12
FR (2km)	QDD-4x100G-FR1 QDD-2x200G-FR4 QDD-400G-FR8 QDD-400G-FR4	400G-4xFR1 400G-2xFR4 400G-FR8 400G-FR4	400G-DR4+	MPO12/4xSN 2xCS/(2xSN) LC Duplex LC Duplex
LR (6km)	QDD-400G-LR4-6	400G-LR4-6		LC Duplex
LR (10km)	QDD-4x100G-LR1 QDD-2x200G-LR4 QDD-400G-LR8 QDD-400G-LR4-10	400G-4xLR1 400G-2xLR4 400G-LR8 400G-LR4-10	400G-DR4++	MPO12/4xSN 2xCS/(2xSN) LC Duplex LC Duplex
ER (30-40km)	QDD-400G-ER8 QDD-400ZR	400G-ER8 400ZR		LC Duplex LC Duplex
ZR (80-120km)	QDD-400ZR QDD-400G-ZR	400ZR 400G-ZR		LC Duplex LC Duplex



Fiber-Optic Connectivity Best Practices from 100G to 800G

Looking ahead, support for 800G capacity and co-packaged optics is a possibility.

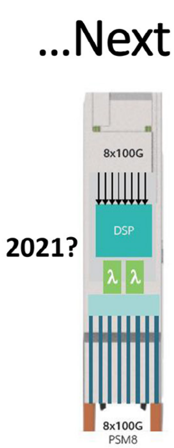
CommScope expects to support 800 Gb/s connectors potentially in the 2021 time frame. Looking ahead to 2024, co-packaged optics are one way to take advantage of application-specific integrated circuits (ASICs) inside the switch and to obtain more capacity without pluggables. Co-packaged optics would go directly to the face of the switch or to a module built on the switch itself, providing quick scaling options in the hyperscale space.

Now is the time to prepare for 400G and above, since network architecture design looks different at higher speeds.

Ken Hall offered the following recommendations for supporting 400G to 800G with existing installations:

1. **Understand what you physically have in place today.** Review your installed system architecture, media, connectivity, fiber count and distance between locations, channel performance (including IL and RL), and current supported speeds.
2. **Consider the infrastructure modification requirements.** This includes knowing if your installed trunk cables use pinned vs. non-pinned MPO. That will be important for connecting MPO equipment cords from an adapter pack at the panel to the pinned MPO transceiver. For direct connect assemblies, choose the correct point to point equipment cords, arrays, and duplex patch cords. Will "transition" assemblies be needed? Confirm polarity to insure transmit goes to receive and vice-versa.
3. **Bring the infrastructure and network teams together.** During network planning, the infrastructure team that is responsible for cabling must talk with the network team. Since decisions made by both teams will affect network timing, performance, and distance, their objectives need to be aligned.

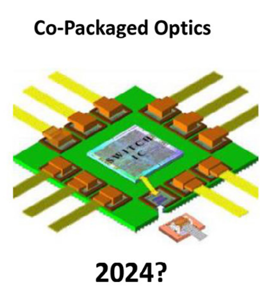
Figure 12: Looking Ahead to 800G Capacity



- **800G MSA** – members promote next generation 100G server connections
- **IEEE Study Group**

800G Capacity QSFP-DD with 100G Electrical Lanes

Reach	Naming Scheme A	Scheme B/C	Connector
VR (50m) SR (100m)	QDD-2x400G-SR4	800G-SR8	MPO16/MPO24
DR (500m)	QDD-2x400G-DR4	800G-DR8	MPO16/MPO24
FR (2km)	QDD-8x100G-FR1 QDD-2x400G-FR4 QDD-800G-FR4/FR8	800G-DR8+ 800G-2xFR4 800G-FR4/FR8	MPO16/MPO24 2xCS/(2xSN) LC Duplex
LR (6km)	QDD-2x400G-LR4-6	800G-2xLR4-6	2xCS/(2xSN)
LR (10km)	QDD-8x100G-LR1 QDD-2x400G-LR4-10	800G-DR8++ 800G-2xLR4-10	MPO16/MPO24 2xCS/(2xSN)
LR (high loss)	QDD-800LR	800LR	LC Duplex
ER (30-40km)	–	–	
ZR (80-120km)	QDD-800ZR	800ZR	LC Duplex



800G Capacity with 100G Electrical Lanes

	Application			
Reach	8X100 Ethernet	4X200 Ethernet	2X400 Ethernet	800G Ethernet
VR (50m)	8X100GBASE-SR1	4X200GBASE-SR2	2X400GBASE-SR4	
SR (100m)	8X100GBASE-SR1	4X200GBASE-SR2	2X400GBASE-SR4	
DR (500m)	8X100GBASE-DR		2X400GBASE-DR4	
FR (2km)	8X100GBASE-FR1		2X400BASE-FR4	800G-FR4/FR8
LR(6km)			2X400GBASE-LR4-6	
LR (10Km)	8X100GBASE-LR1		2X400G-LR4-10	
LR (High Loss)				OIF 800G Coherent
ER (30-40km)				
ZR(80-120km)				OIF 800G Coherent

Fiber-Optic Connectivity Best Practices from 100G to 800G

For new, greenfield installations, the following best practices can help teams plan cabling for 400G, 800G, 1.6T, and beyond:

1. Create cloud-first designs. Design for simple scale and redundancy.
2. Flatten the network by reducing the number of switch tiers. If possible reduce the number of hops to reduce latency and provide additional savings.
3. Highly consider 16 fiber building blocks. These will support legacy and future applications.
4. Network and infrastructure teams should jointly map network electronics and transceiver connectivity applications with trunks, panels, and modules to support various applications.

> When we hit 400G and above, there's a pivot point and the building blocks change. Now is the time to really consider that and collaborate with your partners across the aisle. You want the most efficient and flexible design possible, so you don't have to go back in and re-cable.
>
> *Ken Hall, CommScope*

BIOGRAPHIES

John Kamino

Senior Manager – Multimode Optical Fiber Product Management, OFS

John is a Senior Manager – Multimode Optical Fiber Product Management for OFS. His background includes Product Management, Offer Management, Sales, and Engineering. John has published numerous articles in technical publications and presented at multiple technical conferences. He participates in TIA and IEEE standards activities. He holds a BS degree in Chemical Engineering from the University of Nebraska-Lincoln, and an MBA from Mercer University. He is a member of BICSI and obtained his RCDD in 1994.

Ken Hall, RCDD NTS

Data Center Solutions Architect, Cloud, HyperScale Solutions, CommScope

As Solutions Architect for Cloud-Scale Data Centers at CommScope, Ken is responsible for fiber optic market development, technology, and thought leadership, as well as high speed migration planning for CommScope. Currently focused on portfolio and market planning for 400G+ technologies, Ken has been with CommScope and other acquired companies for over 35 years in global program and project management, technical sales, marketing, and industry standards. He has nine patents to date for fiber optic connectors and infrastructure management solutions.