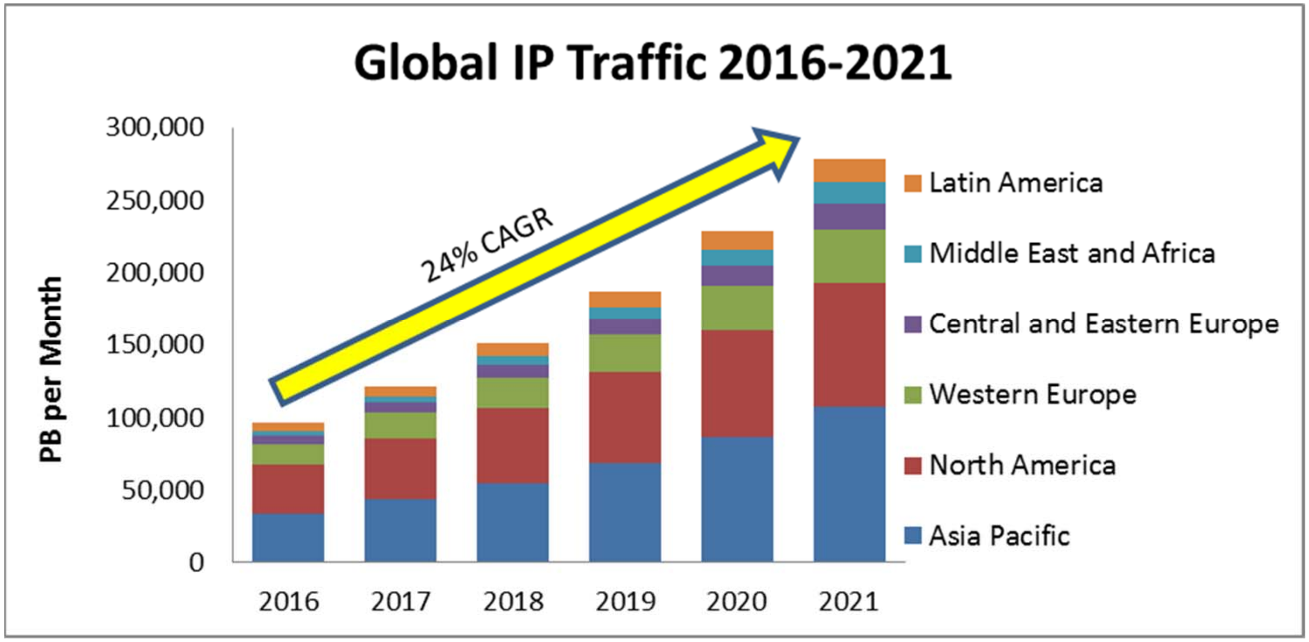
What's New with Enterprise Fiber Standards and Applications

John Kamino
OFS
jkamino@ofsoptics.com

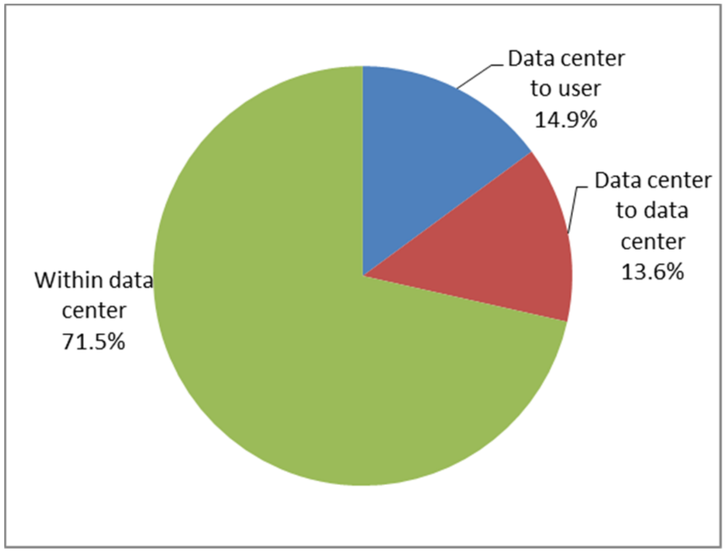
Network IP Traffic Growth

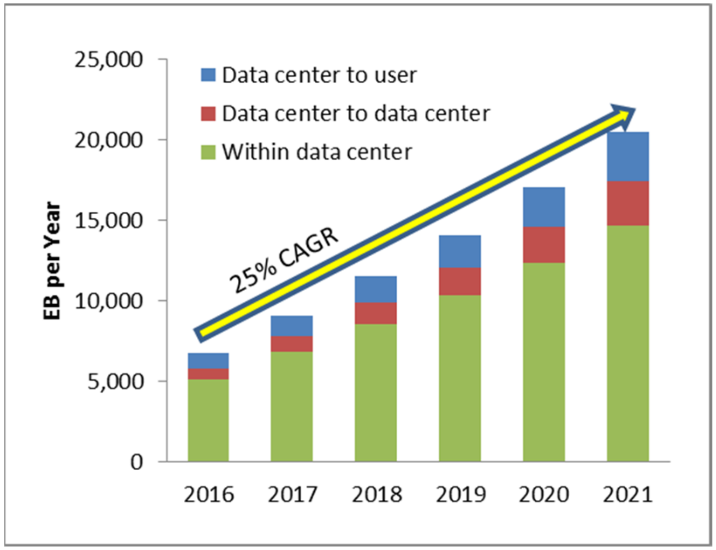


- Global IP traffic will reach 3.3 zettabytes (10^{21}) per year in 2021. By 2020, global IP traffic will reach 2.3 ZB per year
- Global IP traffic will have increased by 127X from 2005 to 2021
- Wireless and mobile devices will account for 63% of traffic in 2021, up from 51% in 2016.

"Cisco Visual Networking Index : Forecast and Methodology, 2016-2021"
6/6/2017

Data Center Traffic

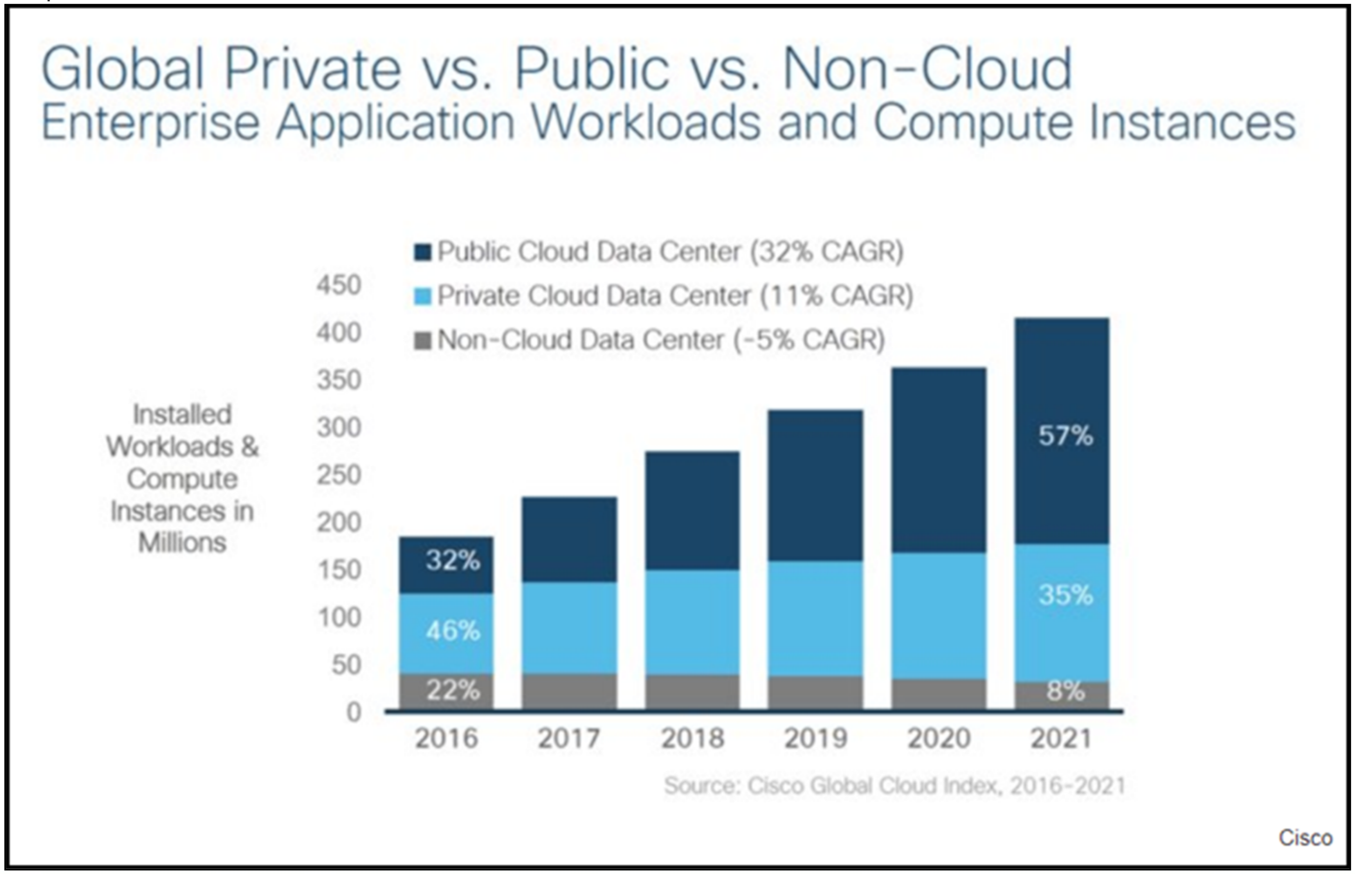




- Global data center traffic will reach 20.6 Zettabytes in 2021, from 6.8 Zettabytes in 2016
- Total East-West traffic will be 85%
- Traffic is growing at a 25% CAGR

Source: Cisco Global Cloud Index:
Forecast and Methodology, 2016-2021
January 2018

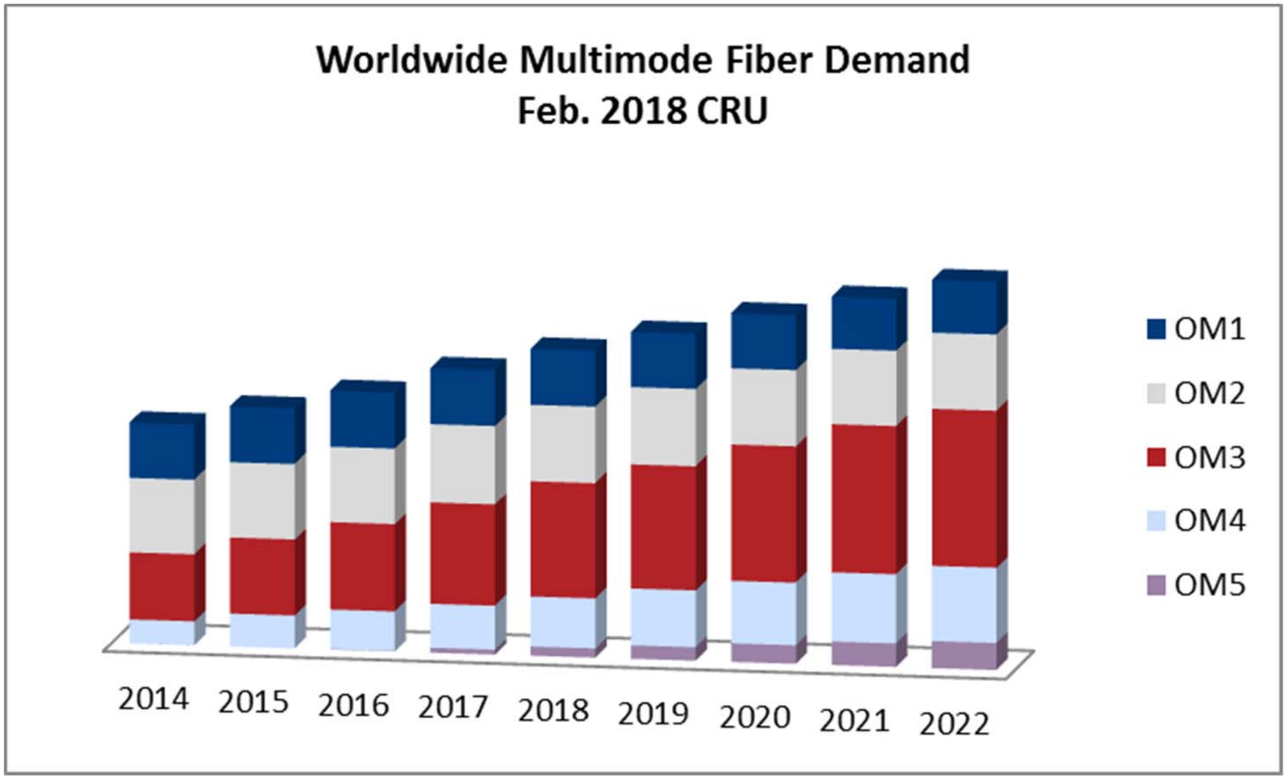
Global Data Center Traffic Growth



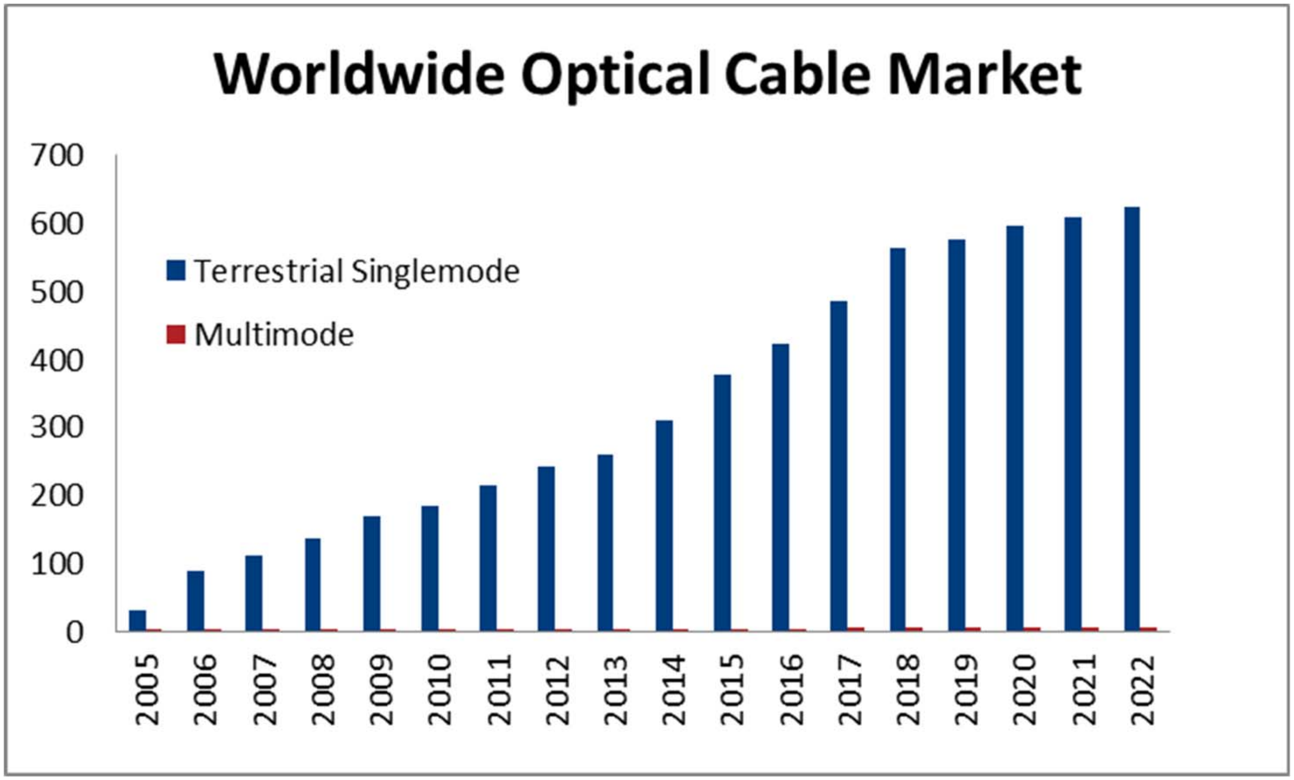
Source: Cisco Global Cloud Index: Forecast and Methodology, 2016-2021 January 2018

Worldwide Multimode Cable Demand by Region

All this demand combines to create multimode volume growth!

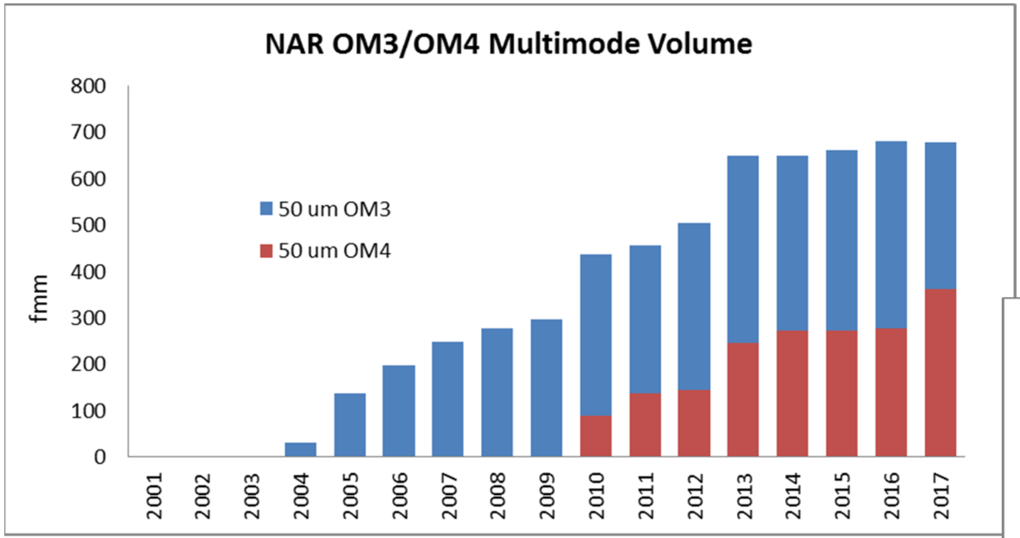


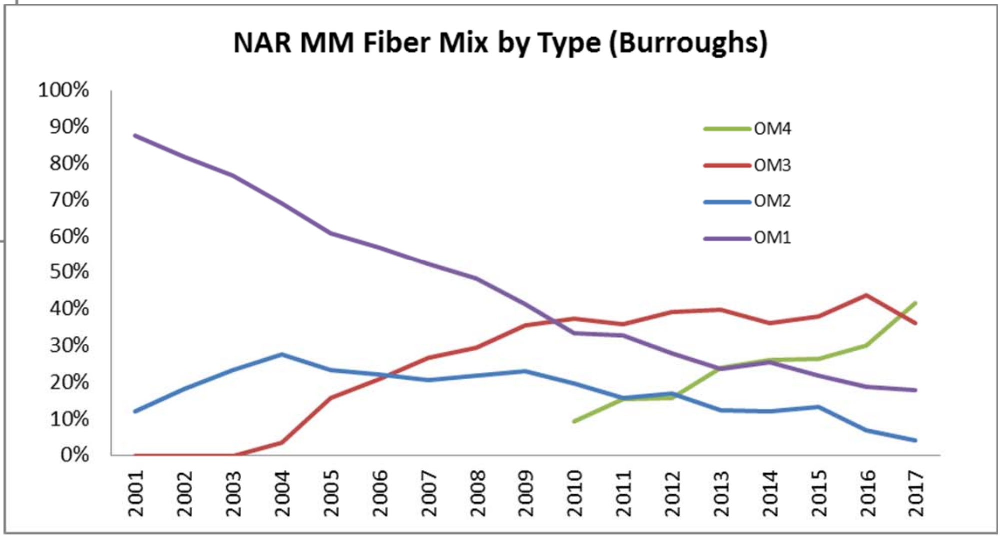
Singlemode vs. Multimode Deployment Worldwide



CRU Telecom Cables Market Outlook
March 2018

Burroughs North America Multimode Fiber Shipments

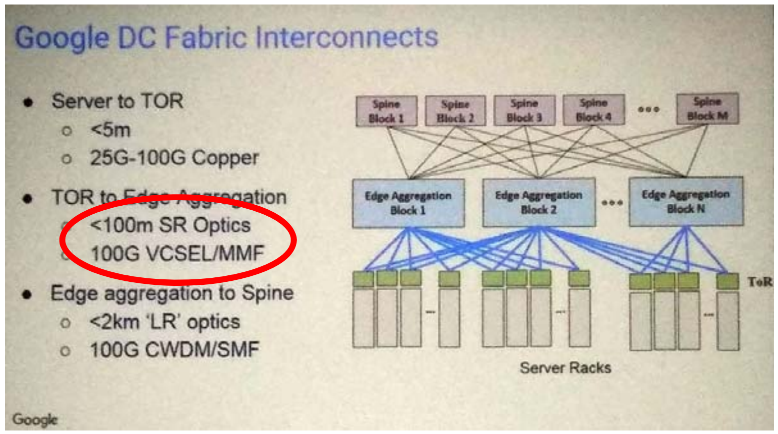


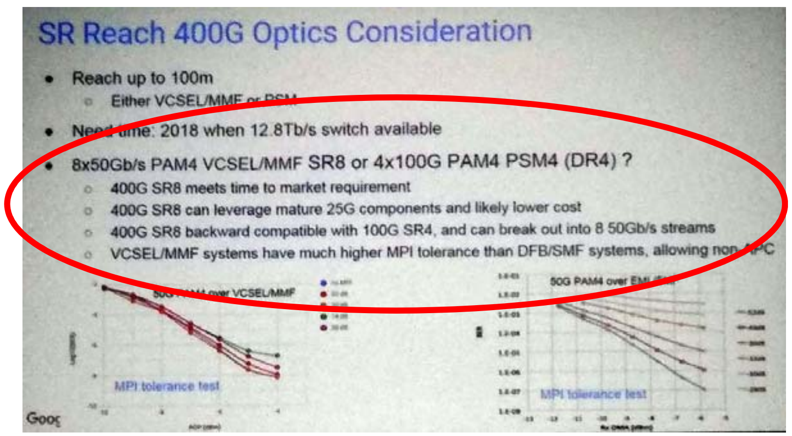


Source: Burroughs Multimode Fiber Reports

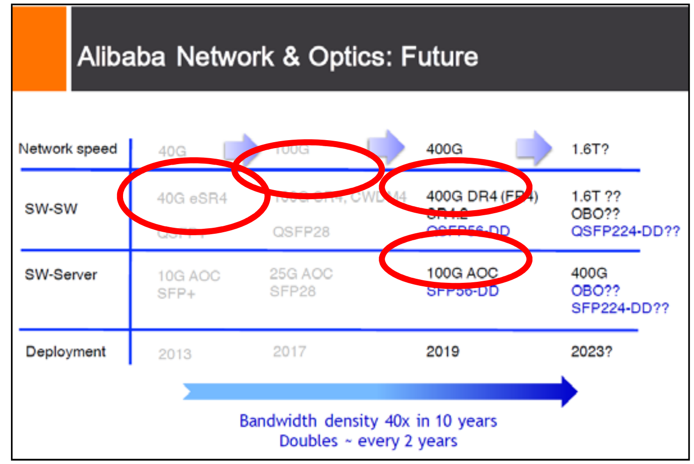
The hyperscale cloud market will continue to deploy multimode fiber!

- Google
  - Deploying 100GBASE-SR4
  - Roadmap to 400GBASE-SR8
  - Z. Shen of Google proposed 400GBASE-SR8 for 802.3cm
- Alibaba
  - Deploying 100GBASE-SR4
  - Roadmap to 400GBASE-SR4.2
- Baidu
  - Deploying 100GBASE-SR4
  - Roadmap to 400GBASE-SR4.2
- Other Big Cloud in US
  - Growing interest for 400G-SR4.2, including breakout





X. Zhou, Google, OFC 2018, San Diego



C. Xie, Alibaba OIF Q4 2018 Shanghai

C. Gang, Baidu, 2018 Optinet, Shanghai

VCSEL-based links over MMF will continue to evolve

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

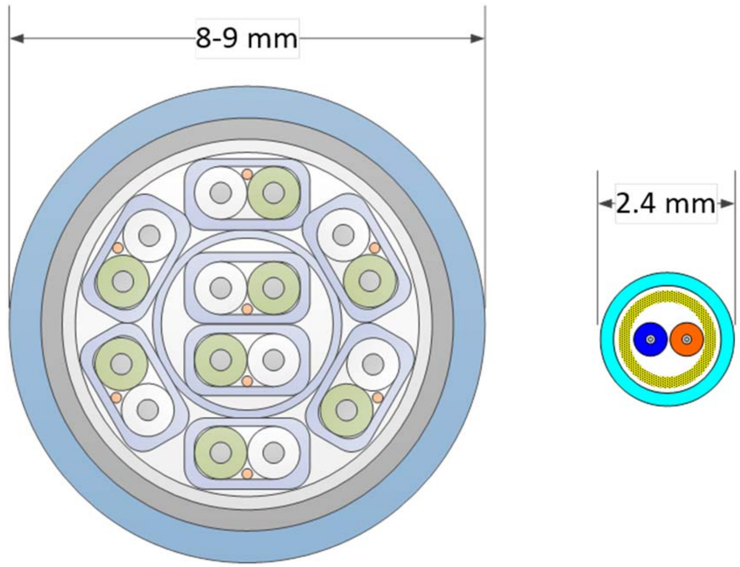
Data Rate	Ethernet Standard or Proprietary Module	# pairs	# λ's	Optical Modulation	OM3	OM4	OM5
100	100GBASE-SR4	4	1	25G NRZ	70	100	Same
100	100G – SWDM4	1	4	25G NRZ	75	100	150
100	100G – BiDi	1	2	50G PAM4	70	100	150
50	50GBASE-SR	1	1	50G PAM4	70	100	Same as OM4
200	200GBASE-SR4	4	1	50G PAM4	70	100	
400	**400GBASE-SR8**	**8**	**1**	**50G PAM4**	**70**	**100**	
400	**400GBASE-SR4.2 (BiDi)**	**4**	**2**	**50G PAM4**	**70**	**100**	
800	**800GBASE-SR8**	**8**	**1**	**100G PAM4**	**30m over ......**		
800	**4/800GBASE-SRm.n**	**4/?**	**TBD**	**100G PAM4**	**100m over MMF**		

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

Existing transceiver types: **Objectives in standardization (proposed values)**; **Projected future technology (anticipated values)**

Why Multimode Fiber instead of Copper? VCSEL-MMF links have greater bandwidth and reach

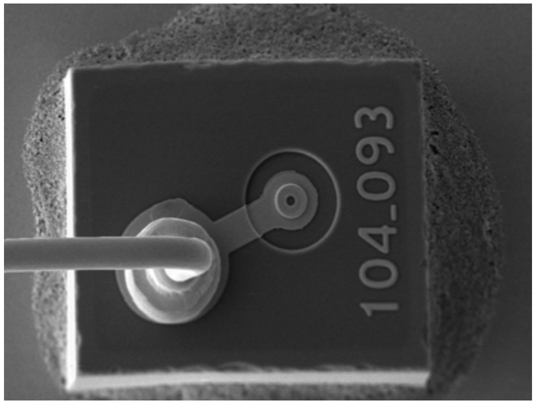
- 40Gb/s reach
  - Twinax – 7 meters (m)
  - Twisted Pair – 30 m
  - OM4 Multimode Fiber – 100 m
    - Can be extended to 400/550m using engineered solutions
- Capacity limited
  - ≥ 10Gb/s speeds very challenging for twisted pair
  - Twinax solutions become unwieldy as speeds go beyond 10G.
    - Not suited for structured cabling
- EMI immunity

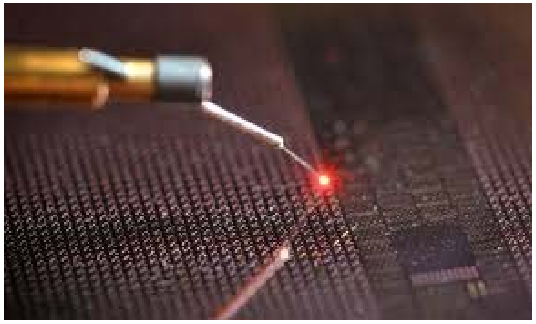


40Gb/s cable solutions – twinax (8 pair) vs. duplex fiber

Why Multimode Fiber instead of Singlemode? VCSEL-MMF links enjoy cost & power advantages

- Relaxed alignment tolerances (~10x) for laser, mux/demux, and connectors
- MMF connectors more resilient to dirt
- Lower drive currents (5-10mA vs. 50-60mA) and on-wafer testing
- Benefits will continue for short reach 400G technologies
  - Gearbox function is needed to convert native 50G PAM-4 to 100G PAM-4 with DR4 & FR4
  - Laser RIN reduction for PAM-4 is as, or more, difficult for DFBs as VCSELs
  - Packaging for 1310nm sources at 100 Gb/s per lane PAM4 has required significant development





All these combine to give multimode links a continued cost advantage over singlemode links

Fiber Standards

Multimode Fiber 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 (OFLc)		Bandwidth (MHz-km): Effective Modal Bandwidth (EMB) (also known as Laser BW)	
	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 62.5um fiber, but can also be a 50um fiber.*
(2) *OM2 is typically a 50um fiber, but can also be a 62.5um fiber.*
(3) *"b" designates Bend-Insensitive*
(4) *ISO/IEC 11801 has a max. cabled attenuation of 3.5dB/km*

Single-Mode Fiber Types

Fiber Type	Industry Standards				Attenuation Typical Cabled Max. (dB/km)		
	ISO/IEC 11801 November 2017	IEC 60793-2-50	TIA/EIA	ITU-T	1310 nm	1385 nm	1550 nm
~~Std SM~~	~~OS1~~	~~B1.1~~	~~492CAAA~~	~~G.652.A or B~~	~~1.0~~	~~N.A.~~	~~1.0~~
Std SM	OS1a	B1.3	492CAAB	G.652.C or D	1.0	1.0	1.0
Low Water Peak SM	OS2[1]	B1.3	492CAAB	G.652.C or D	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"

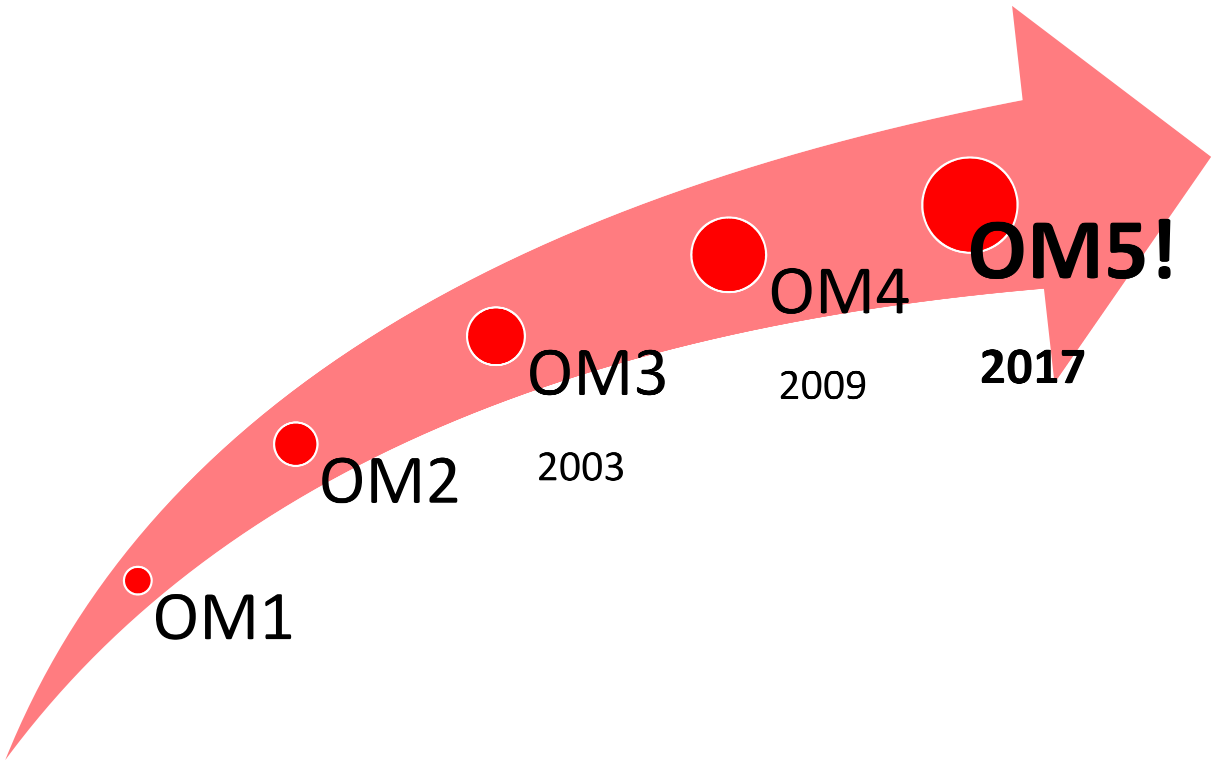
TIA/EIA-492CAAA "Detail Specification for Class IVa Dispersion-Unshifted Single-Mode Optical Fibers"

TIA/EIA-492CAAB "Detail Specification for Class IVa Dispersion-Unshifted Single-Mode Optical Fibers with Low Water Peak"

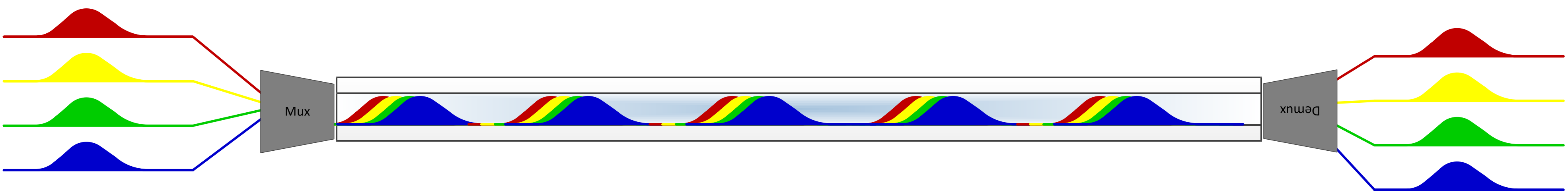
ITU-T Single-mode Standards (commonly used in service provider networks)

ITU-T Standard	ISO/IEC Standard	Bend Loss Radius	Bend Loss (Max loss/turn @ 1550 nm)	Nominal Mode Field @ 1310 nm	Comments
G652.D	OS2	30 mm	0.001 dB (0.1 dB @ 100 turns)	8.6 - 9.2	"Standard" Single-mode
G657.A1	OS2	10 mm	0.75 dB	8.6 - 9.2	G652.D Compliant "Bend-Insensitive" Single-Mode
G657.A2	OS2	7.5 mm	0.5 dB	8.6 - 9.2	G652.D Compliant "Bend-Insensitive" Single-Mode
G657.B3	Non-compliant (chromatic dispersion, low water peak)	5 mm	0.15 dB	8.6 - 9.2	G652.D Compatible "Bend-Insensitive" Single-Mode

Multimode Fiber Evolution



What can you do with OM5 Fiber?



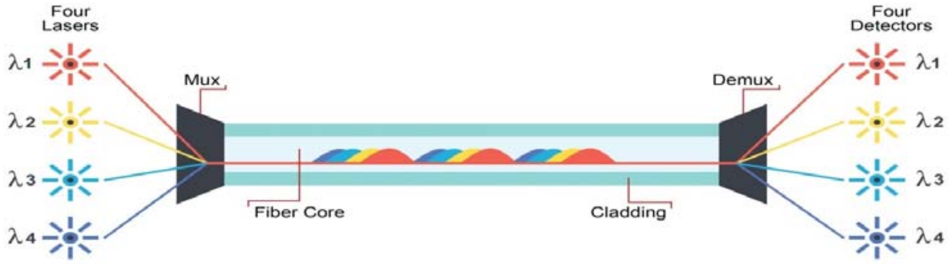
OM5 Fiber enables DUPLEX fiber links to support 100Gb/s speeds on a single fiber using:

1. 2 wavelengths, each operating at 50Gbps
2. 4 wavelengths, each operating at 25Gbps

Standards Objectives

- Support 100Gb/s transmission on a single fiber over 4 wavelengths
- Wavelengths > 850nm benefit from increasing chromatic bandwidth.
- Low-cost WDM needs ~ 30nm spacing.
  - Resulting target wavelength region: 850nm to at least 950nm.
- Continue to support legacy 850nm OM4 applications
  - Maintain OM4 backward compatibility

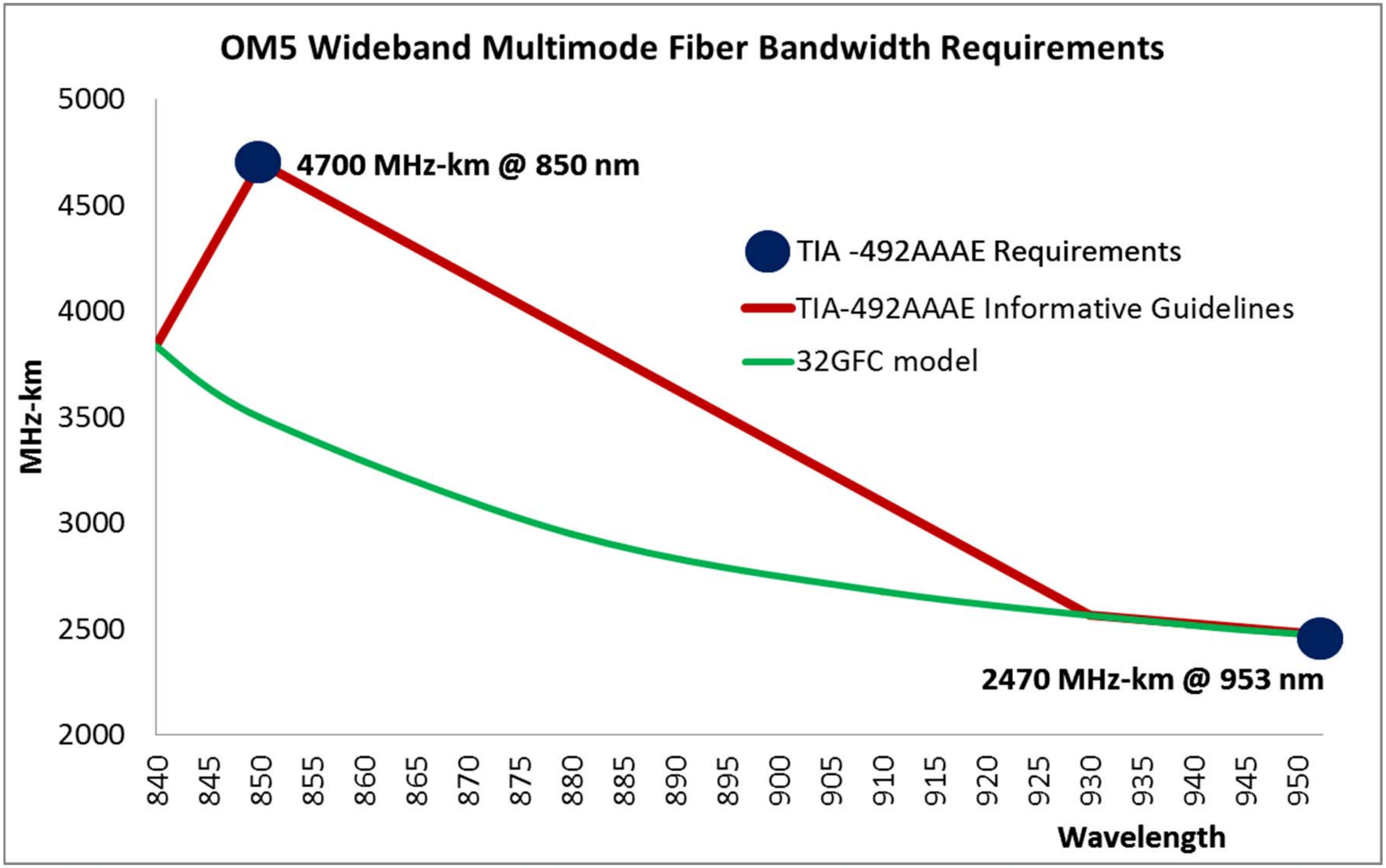
Standard Multimode Fiber



WideBand Multimode Fiber

Differences between OM4 and WideBand OM5 fiber

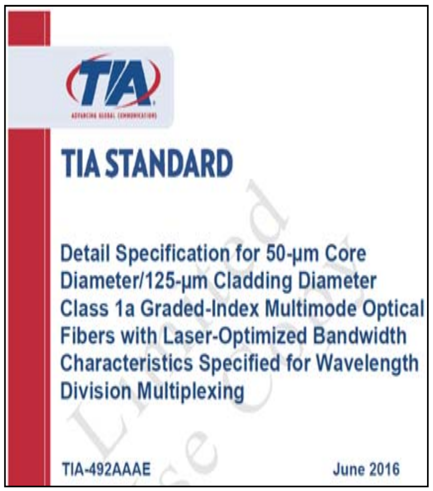
	OM4 Multimode Fiber	WideBand (OM5) Multimode Fiber
Zero Dispersion Wavelength	$1295 \le \lambda_o \le 1340$ nm	$1297 \le \lambda_o \le 1328$ nm
Zero Dispersion Slope	$S_0 \le 0.105$ ps/nm$^2\cdot$km for $1295 \le \lambda_o \le 1310$ nm, and $\le 0.000375(1590-\lambda_o)$ ps/nm$^2\cdot$km for $1310 \le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

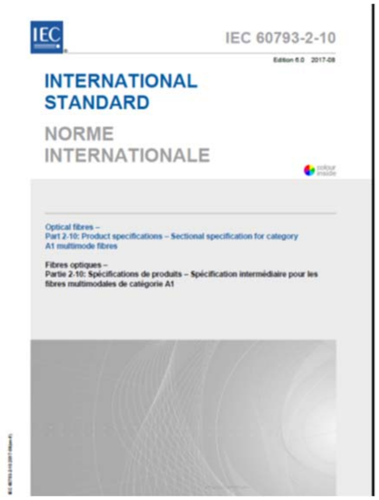


OM5 Wideband Multimode Fiber Bandwidth Requirements
5000
4500
4000
3500
3000
2500
2000
MHz-km
4700 MHz-km @ 850 nm
TIA -492AAAE Requirements
TIA-492AAAE Informative Guidelines
32GFC model
2470 MHz-km @ 953 nm
840 845 850 855 860 865 870 875 880 885 890 895 900 905 910 915 920 925 930 935 940 945 950
Wavelength

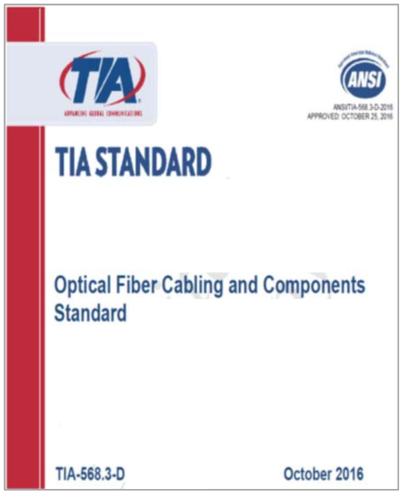
Wideband OM5 Standardization
Improved performance with multiple wavelengths

- OM5 MMF extends the 850nm performance of OM4 to 953nm
- Standards:
  - **Fiber:** TIA-492AAAE (2016), IEC 60793-2-10 ed. 6 (August 2017)
  - **Structured Cabling:** ANSI/TIA-568.3-D (2016), ISO/IEC 11801-1 (November 2017)





Fiber Standards

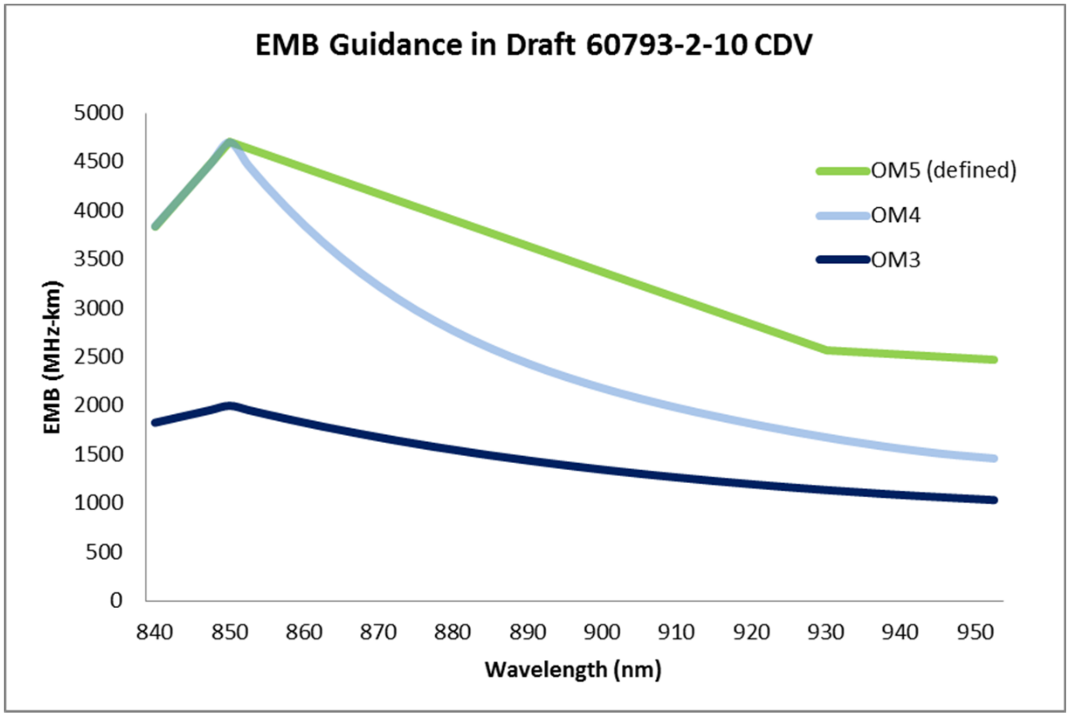


Structured Cabling Standards

Work in Process

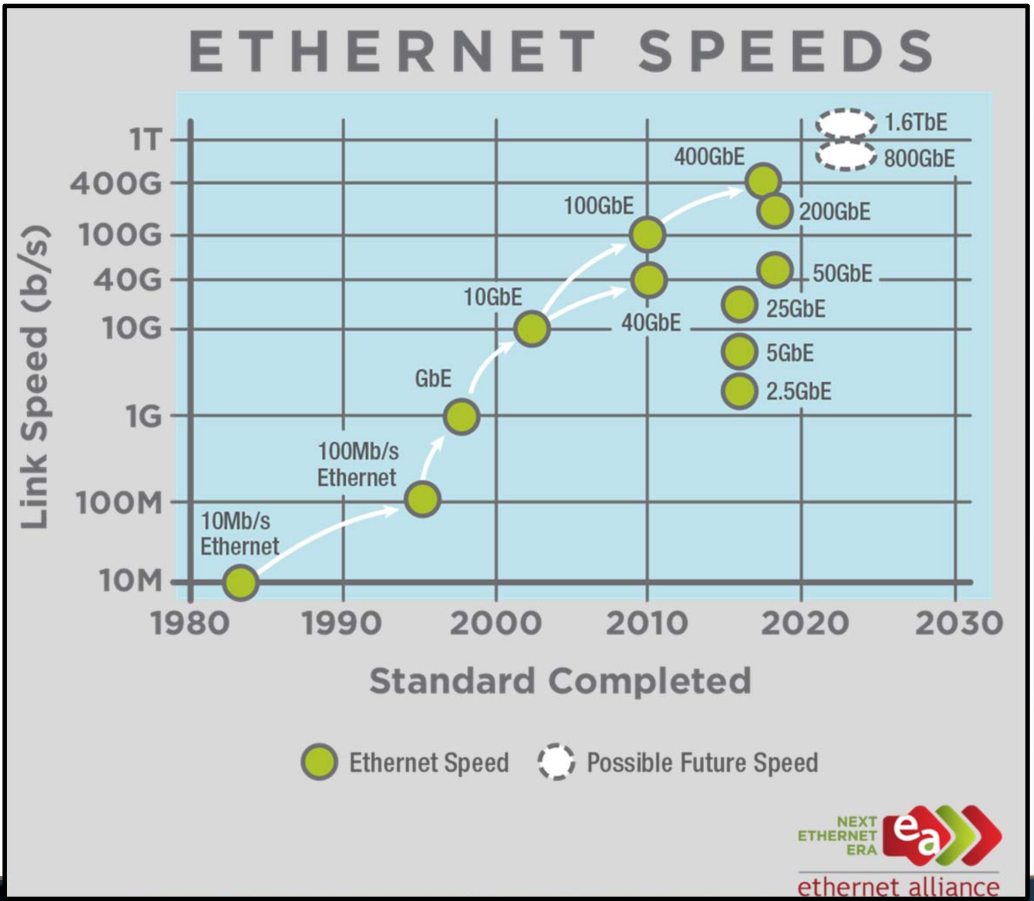
- IEC 60793-2-10 revisions
  - Proposal to add guidance for OM3 and OM4 bandwidth from 840nm to 953nm

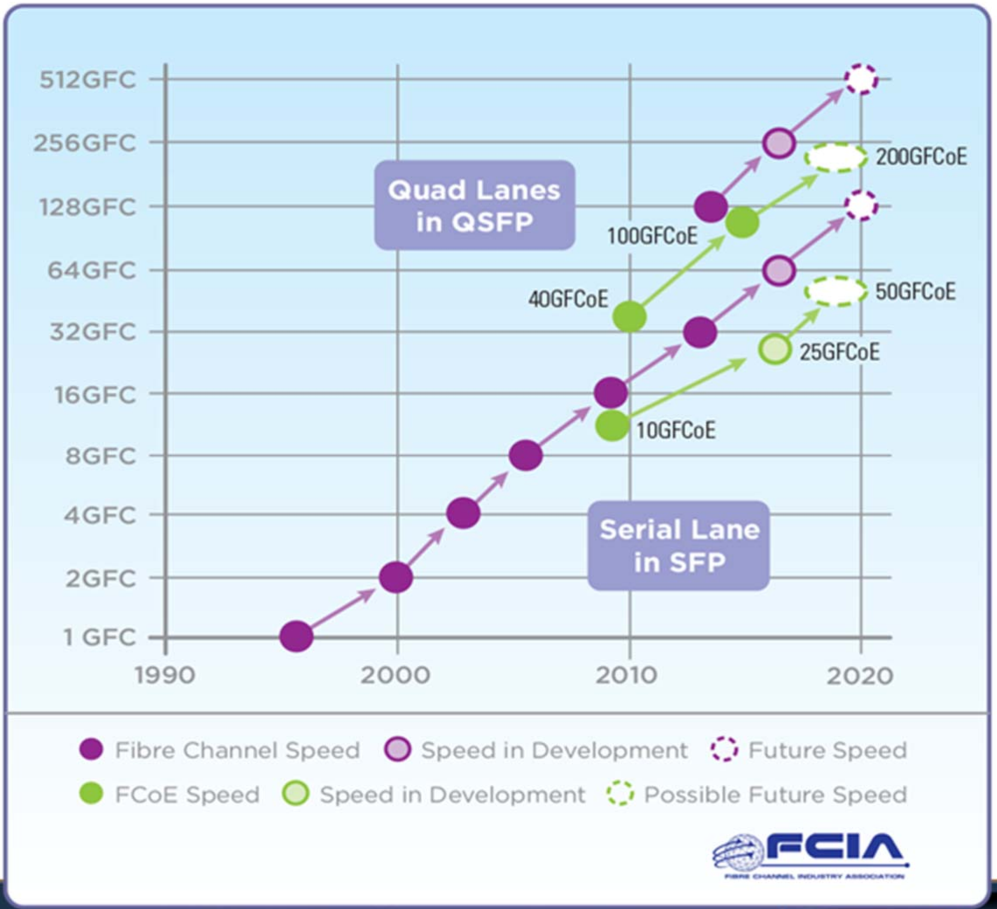
- TIA 492AAAx revisions
  - Proposal to replace current TIA-492-AAAA, AAAB, AAAC, AAAD, and AAAE with a single document, adapting IEC 60793-2-10 to become TIA-492-AAAF.



Application Standards

Evolution of Short Reach Applications





Latest Ethernet Standards

40G & 100G Ethernet (IEEE 802.3ba)

PMD	Link Distance	Fiber Count and Media Type	Technology
40GBASE-SR4	100 m OM3 150 m OM4	8-f MMF (12-f MPO)	4x10G parallel NRZ 850nm
40GBASE-eSR4 (extended reach)*	300 m OM3 400m OM4	8-f MMF (12-f MPO)	4x10G parallel NRZ 850nm
40GBASE-LR4	10 km	2-f SMF	4x10G CWDM NRZ 4 wavelengths around 1300nm
100GBASE-SR10	100 m OM3 150 m OM4	20-f SMF (24-f MPO)	10x10G parallel NRZ 850 nm
100GBASE-LR4	10 km	2-f SMF	4x25G CWDM NRZ 4 wavelengths around 1300nm
100GBASE-ER4	40 km	2-f SMF	4x25G CWDM NRZ 4 wavelengths around 1300nm

* non-standard solution

Published in 2010

40G & 100G Ethernet (IEEE 802.3bm)

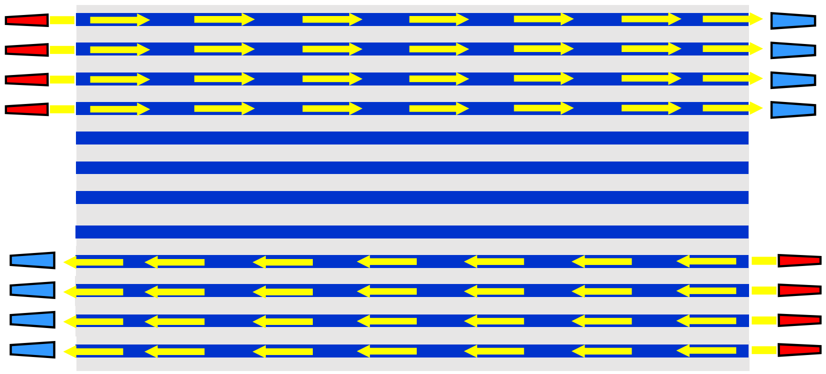
PMD	Link Distance	Fiber Count and Media Type	Technology
40GBASE-ER4	30 km (40 km engineered link)	2-f SMF	4x10G CWDM NRZ 4 wavelengths around 1300nm
100GBASE-SR4	70 m OM3 100 m OM4	8-f MMF (12-f MPO)	4x25G parallel NRZ 850 nm
100GBASE-eSR4 (extended reach)*	200-300 m OM3 300-400 m OM4	8-f MMF (12-f MPO)	4x25G parallel NRZ 850 nm

Published in 2015

*** non-standard solution**

High Speed Short Reach Technologies: Multiple Fiber Parallel Systems

- One 12-fiber cable
  - duplex link
  - 8 active fibers
- 12 Fiber MPO connector
- One wavelength per fiber
- 4 x 10 Gb/s – 40Gb/s
- 4 x 25 Gb/s -100Gb/s



Seamless upgrade from 40G to 100G system up to 100m!

25 Gb/s Ethernet (IEEE 802.3by)

PMD	Link Distance	Fiber Count and Media Type	Technology
25GBASE-SR	100 m OM4	2-f MMF	1x25G NRZ

Published July 2016

200/400 Gb/s Ethernet (IEEE802.3bs)

PMD	Link Distance	Fiber Count and Media Type	Technology
400GBASE-SR16	100 m OM4/OM5 (32-f MPO)	32-f MMF	16x25G parallel NRZ 850nm
400GBASE-DR4	500 m	8-f SMF	4x100G parallel PAM4 1300nm
400GBASE-FR8	2 km	2-f SMF	8x50G CWDM PAM4 8 wavelengths around 1300nm
400GBASE-LR8	10 km	2-f SMF	8x50G CWDM PAM4 8 wavelengths around 1300nm
200GBASE-DR4	500 m	8-f SMF	4x50G Parallel PAM4 1300nm
200GBASE-FR4	2 km	2-f SMF	4x50G CWDM PAM4 4 wavelengths around 1300nm
200GBASE-LR4	10 km	2-f SMF	4x50G CWDM PAM4 4 wavelengths around 1300nm

Published Dec. 2017

25 Gb/s Ethernet (IEEE 802.3cc)

PMD	Link Distance	Fiber Count and Media Type	Technology
25GBASE-LR	10 km SMF	2-f SMF	1x25G NRZ
25GBASE-ER	40 km SMF	2-f SMF	1x25G NRZ

Published Jan. 2018

LC Duplex SWDM transceivers (non-standards based)

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

* Announced

SWDM Alliance

- Industry alliance to promote the use of SWDM technology
  - Create and promote an industry ecosystem that fosters adoption of SWDM for cost effective data center interconnections over duplex multimode fiber at or above 40 Gbps
  - The founding members of the SWDM Alliance are CommScope, Corning, Dell, Finisar, H3C, Huawei, Juniper, Lumentum, and OFS.

http://www.swdm.org/

SWDM Multi-Source Agreement (MSA)

- Announced March 16, 2017
- Defined optical specifications for four-wavelength SWDM to transmit 40 Gb/s and 100 Gb/s Ethernet signals (“40 GE SWDM4” and “100 GE SWDM4,” respectively)
- http://www.swdm.org/msa/

400G BiDi MSA

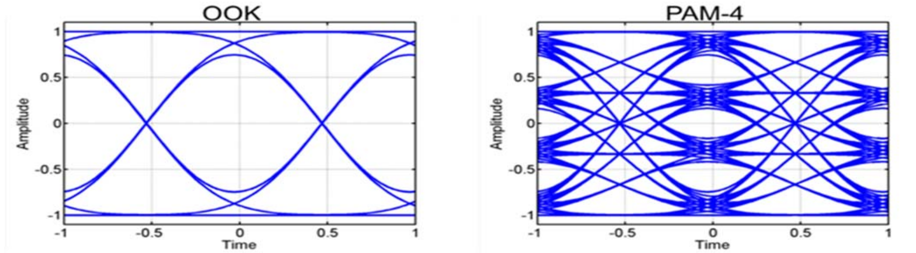
- Announced July 9, 2018
- Define “optical data link specifications and promoting adoption of interoperable 100 Gb/s and 400 Gb/s optical transceivers for 100 meter link distance based on a dual wavelength bidirectional transmission technology in multi-mode optical fiber (MMF).”
- Reach
  - 70m OM3
  - 100m OM4
  - 150m OM5
- Specifications currently in development
- https://www.400gbidi-msa.org/

Latest Ethernet Developments

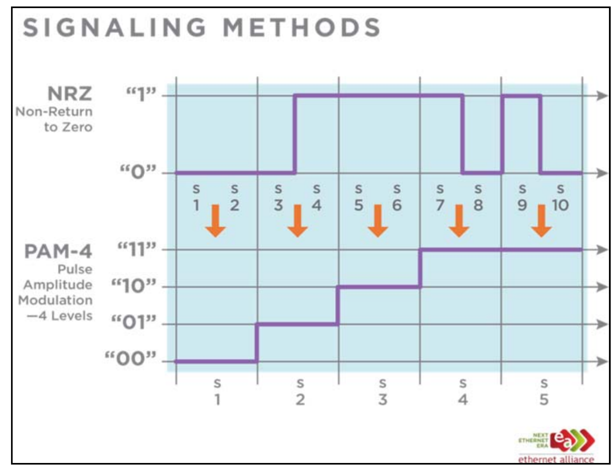
Multilevel signaling

PAM-4

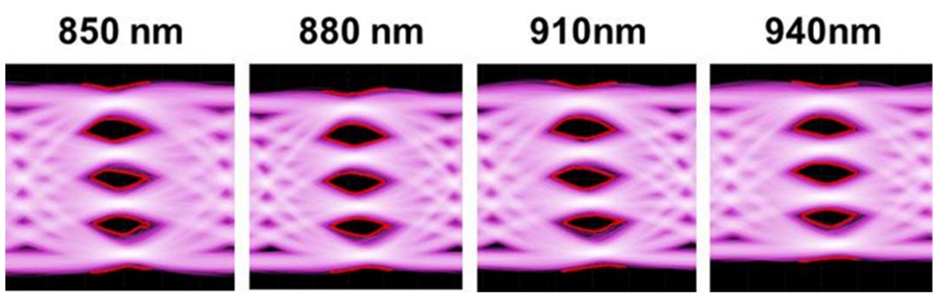
Increases the bit rate 2x

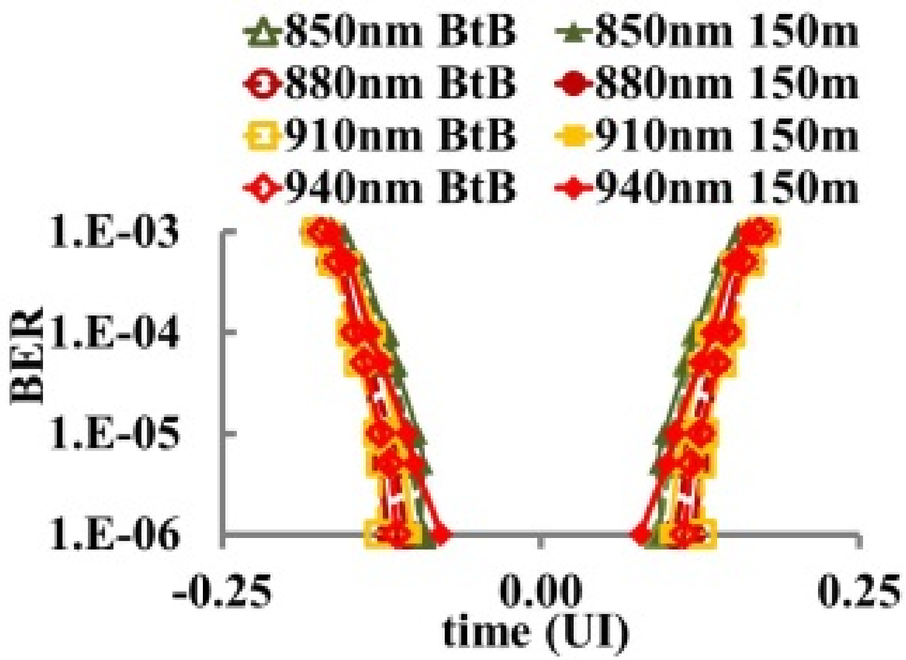


- Will be included in IEEE and FC next generation solutions
  - Will leverage CWDM efforts to further expand fiber capacity
  - Enables 50Gb/s/lane rate
- Advanced modulation formats require higher receiver sensitivity than OOK
  - Have to accommodate "multiple eyes" within same vertical interval
- Receiver sensitivity requirements can be reduced via Equalization and/or FEC



51.56 Gbps PAM4 Transmission over LaserWave WideBand (OM5) Fiber





Demonstrated capacity of 206 Gbps over a single multimode fiber!

50/100/200 Gb/s Ethernet (IEEE 802.3cd)

PMD	Link Distance	Fiber Count and Media Type	Technology
50GBASE-SR	100 m OM4/OM5	2-f MMF	1x50G PAM-4 850nm
50GBASE-FR	2 km	2-f SMF	1x50G PAM-4 1300nm
50GBASE-LR	10 km	2-f SMF	1x50G PAM-4 1300nm
100GBASE-SR2	100 m	4-f MMF	2x50G PAM-4 850nm
100GBASE-DR	500 m	2-f SMF	1x100G PAM4 1300nm
200GBASE-SR4	100 m	8-f MMF	4x50G parallel PAM-4 850nm

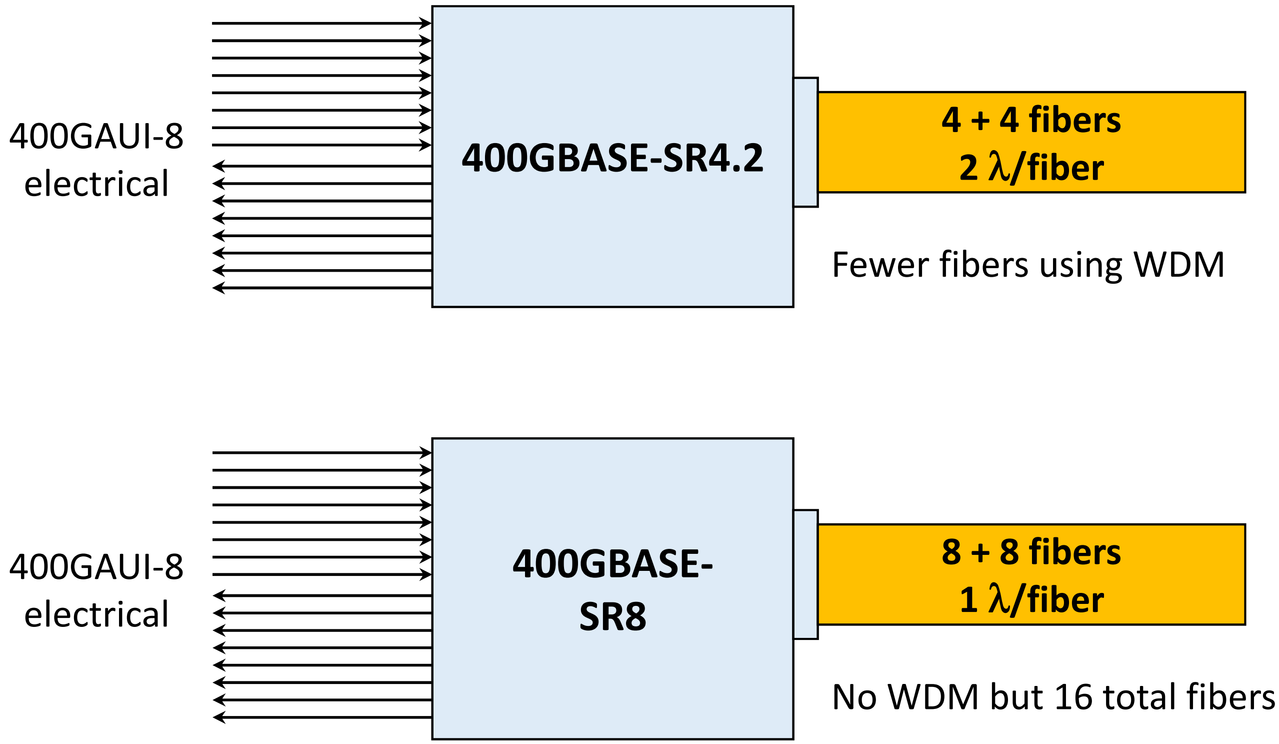
Active - Publication Expected 2018

400 Gb/s Ethernet (IEEE 802.3cm)

PMD	Link Distance	Fiber Count and Media Type	Technology
400GBASE-SR8	100 m OM4/OM5	16-f MMF	8x50G PAM-4 850nm
400GBASE-SR4.2	100 m OM4 150 m OM5	8-f MMF	4x2x50G parallel PAM-4 Two Wavelength solution 850nm/910nm Bi-Directional (BiDi)

Task Force Approved May 2018

400G MMF under consideration in Ethernet 802.3cm



400GBASE-SRx.y

\# fibers

\# wavelengths/fiber

Both are 8x50G electrical to 8x50G optical

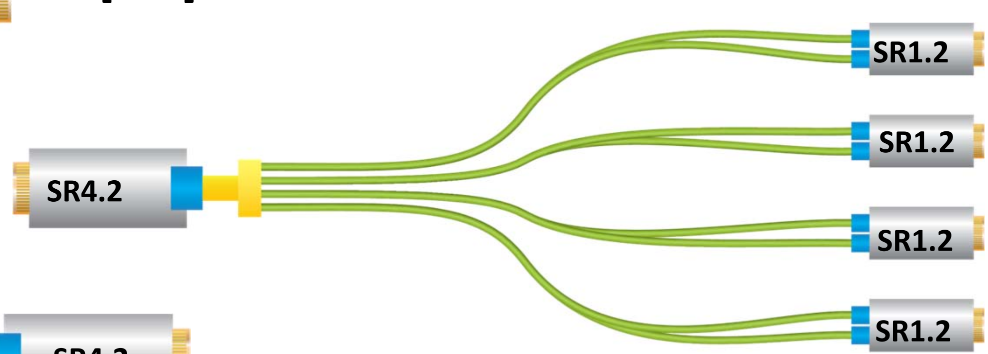
400GBASE-SR4.2

- First standards based application using wavelength division multiplexing (WDM)
  - Takes advantage of Wideband OM5 fiber
    - Baseline adopted with reach objectives
      - 70m OM3
      - 100m OM4
      - 150m OM5
- Two wavelength solution
- New nomenclature
  - SRx.y
    - X – number of fibers
    - Y – number of wavelengths
- Standard 12-fiber MPO connector interface, using 8 active fibers
- Proprietary/MSA solutions currently available for 40/100G WDM duplex links

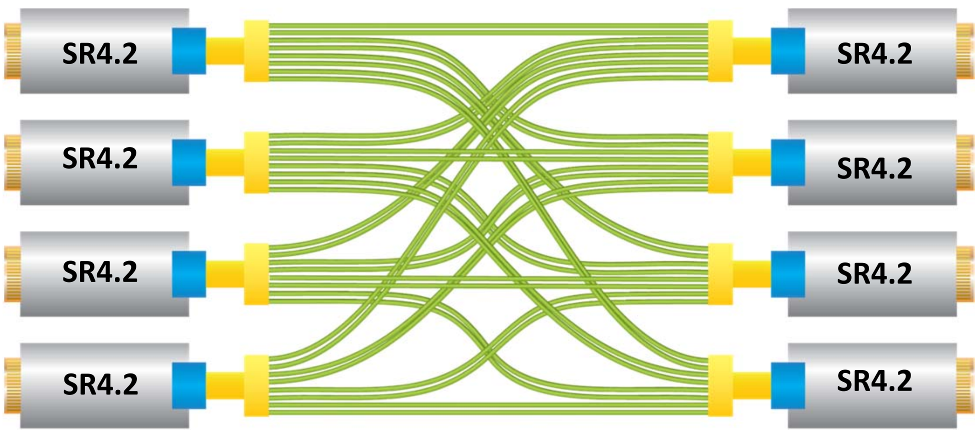
ofs A Furukawa Company

400GBASE-SR4.2

[Left] SR4.2 Low Cost Point-to-Point Link



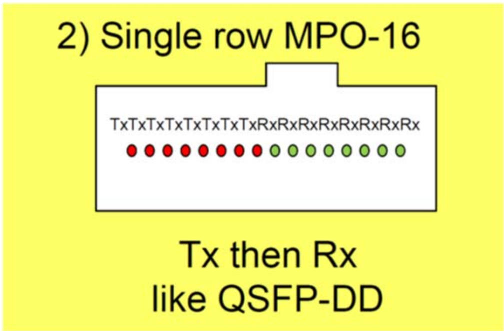
[Right] SR4.2 4 x 100G breakout



[Left] 4 x 4 fiber shuffle allows a 32-port 400G switch to be used as a 128-port 100G switch

400GBASE-SR8

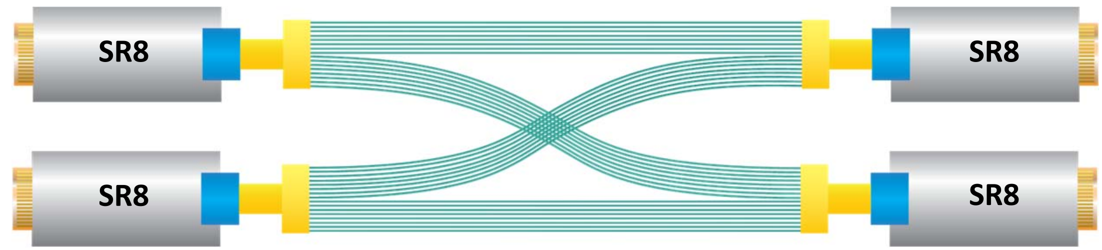
- 400GBASE-SR8 Baseline proposal accepted May 2018
  - Eight fiber pairs
  - Reach:
    - 100 meters over OM4/OM5
    - 70 meters over OM3
  - Two connector choices (Media Dependent Interfaces [MDIs]):

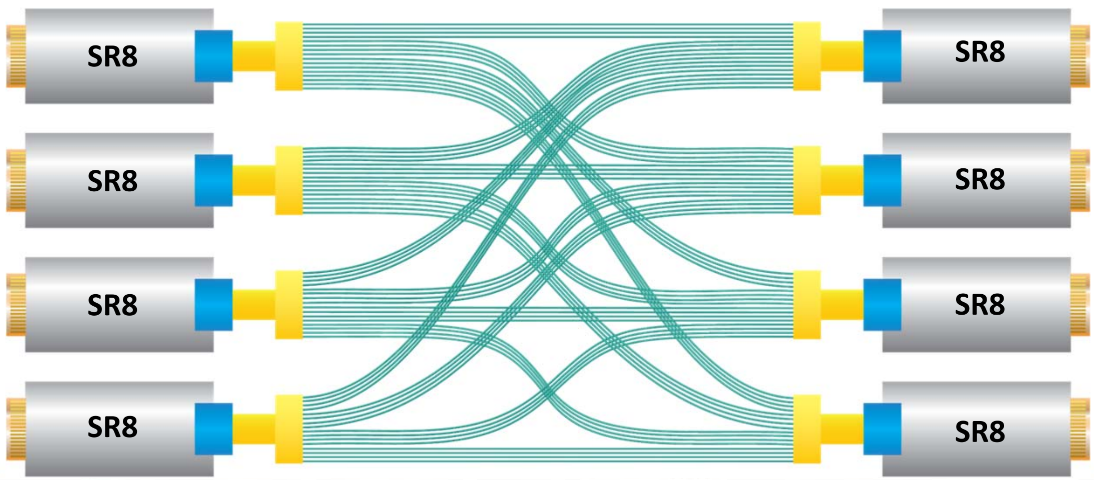


400GBASE-SR8

[Left] SR8 point-to-point link

[Right] 2 x 2 fiber shuffle allows a 32-port 400G switch to be used as 64 port 200G switch



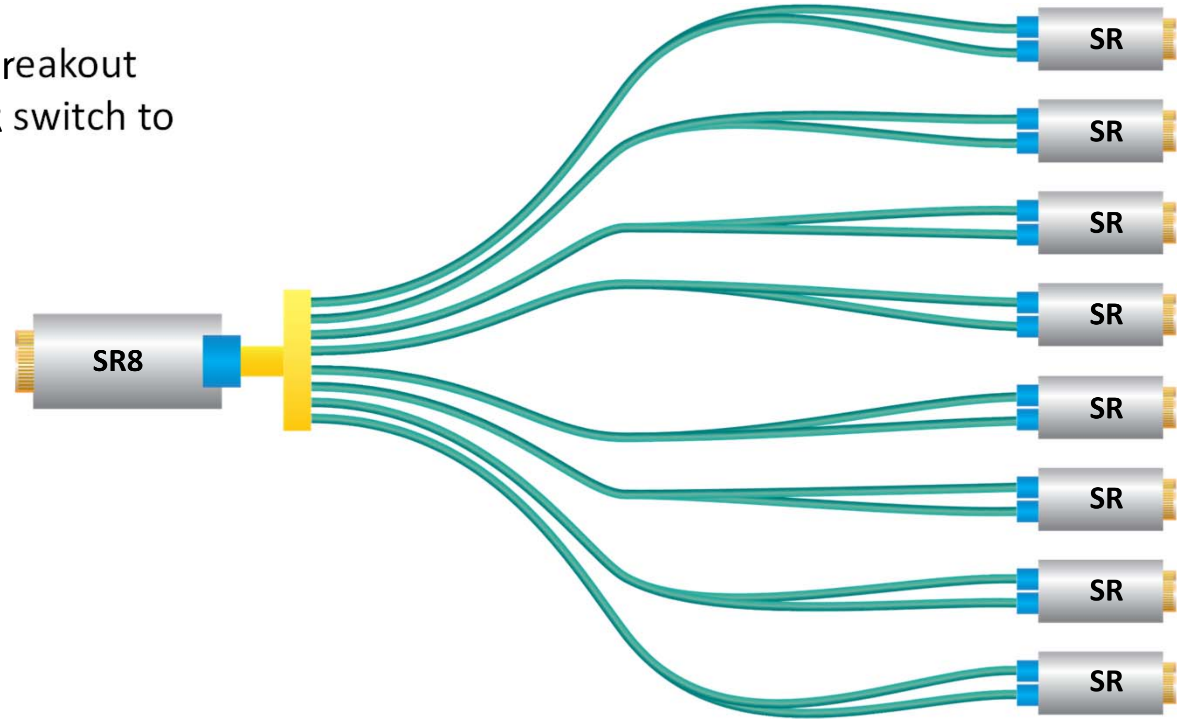


[Left] 4 x 4 fiber shuffle allows a 32-port 400G switch to be used as 128 port 100G switch

400GBASE-SR8 breakout

[Right] SR8 module shown in 8 x 50G breakout mode to connect a 400G port on a TOR switch to 8 x 50G server ports

May be short reach AOC application



VCSEL-based links over MMF will continue to evolve

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

Data Rate	Ethernet Standard or Proprietary Module	# pairs	# λ's	Optical Modulation	OM3	OM4	OM5
100	100GBASE-SR4	4	1	25G NRZ	70	100	Same
100	100G – SWDM4	1	4	25G NRZ	75	100	150
100	100G – BiDi	1	2	50G PAM4	70	100	150
50	50GBASE-SR	1	1	50G PAM4	70	100	Same
100	100GBASE-SR2	2	1	50G PAM4	70	100	
200	200GBASE-SR4	4	1	50G PAM4	70	100	
400	**400GBASE-SR8**	**8**	**1**	**50G PAM4**	**70**	**100**	
400	**400GBASE-SR4.2**	**4**	**2**	**50G PAM4**	**70**	**100**	**150**
800	**800GBASE-SR8**	**8**	**1**	**100G PAM4**	**30m over MMF**		
4/800	**4/800GBASE-SRm.n**	**4/8**	**TBD**	**100G PAM4**	**100m over MMF**		

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

Existing transceiver types; Objectives in standardization (proposed values) ; Projected future technology (anticipated values)

Latest Fiber Channel Standards

32GFC – FC-PI-6

Variant	Link Distance	Fiber Count and Media Type	Technology
3200-M5-SN-S	20 m OM2	2-f MMF	1x28G NRZ 850nm
3200-M5E-SN-S	70 m OM3	2-f MMF	1x28G NRZ 850nm
3200-M5F-SN-I	100 m OM4	2-f MMF	1x28G NRZ 850nm
3200-SM-LC-L	10 km	2-f SMF	1x28G NRZ 1300nm

Published in 2013

128GFC – FC-PI-6P

Variant	Link Distance	Fiber Count and Media Type	Technology
128GFC-SW4	70 m OM3 100 m OM4	8-f MMF	4x28G parallel NRZ 850nm
128GFC-PSM4	500 m	8-f SMF	4x28G parallel NRZ 1300nm
128GFC-CWDM4	2 km	2-f SMF	4x28G CWDM NRZ 4 wavelengths around 1300nm

Published in 2016

64GFC – FC-PI-7

Variant	Link Distance	Fiber Count and Media Type	Technology
64GFC	100 m OM4/OM5	2-f MMF	PAM-4
64GFC	10 km	2-f SMF	PAM-4

- Letter ballot is expected in 2018
- Split off 256GFC in September 2017 – separate document

256GFC – FC-PI-7P

Variant	Link Distance	Fiber Count and Media Type	Technology
256GFC	100 m OM4/OM5	8-f MMF	PAM-4
256GFC	2 km	2-f SMF	PAM-4

- New project initiated October 2017
- Initial Public Review targeted for December 2018

Conclusions

- Bandwidth demands continue to grow, and application speeds are increasing to support those needs.
- Enterprise cloud, hybrid and hyperscale data centers will continue to deploy multimode fiber links
- Multimode transceivers are evolving to support higher speed links needed in the newest data centers, including the hyperscale market
- Multimode fiber links continue to have advantages over competing media types

Thank You!