"What Is Going On With Data Center Standards and Technology?"

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2017
BICSI CANADIAN
CONFERENCE & EXHIBITION
MAY 8-11 • VANCOUVER, BRITISH COLUMBIA, CANADA

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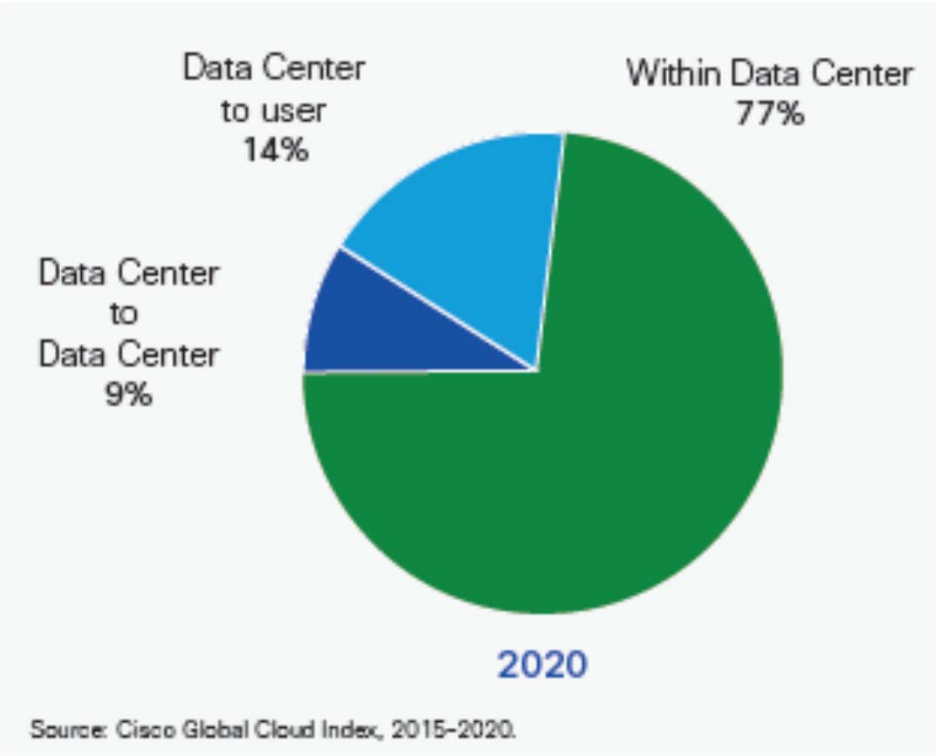
Agenda

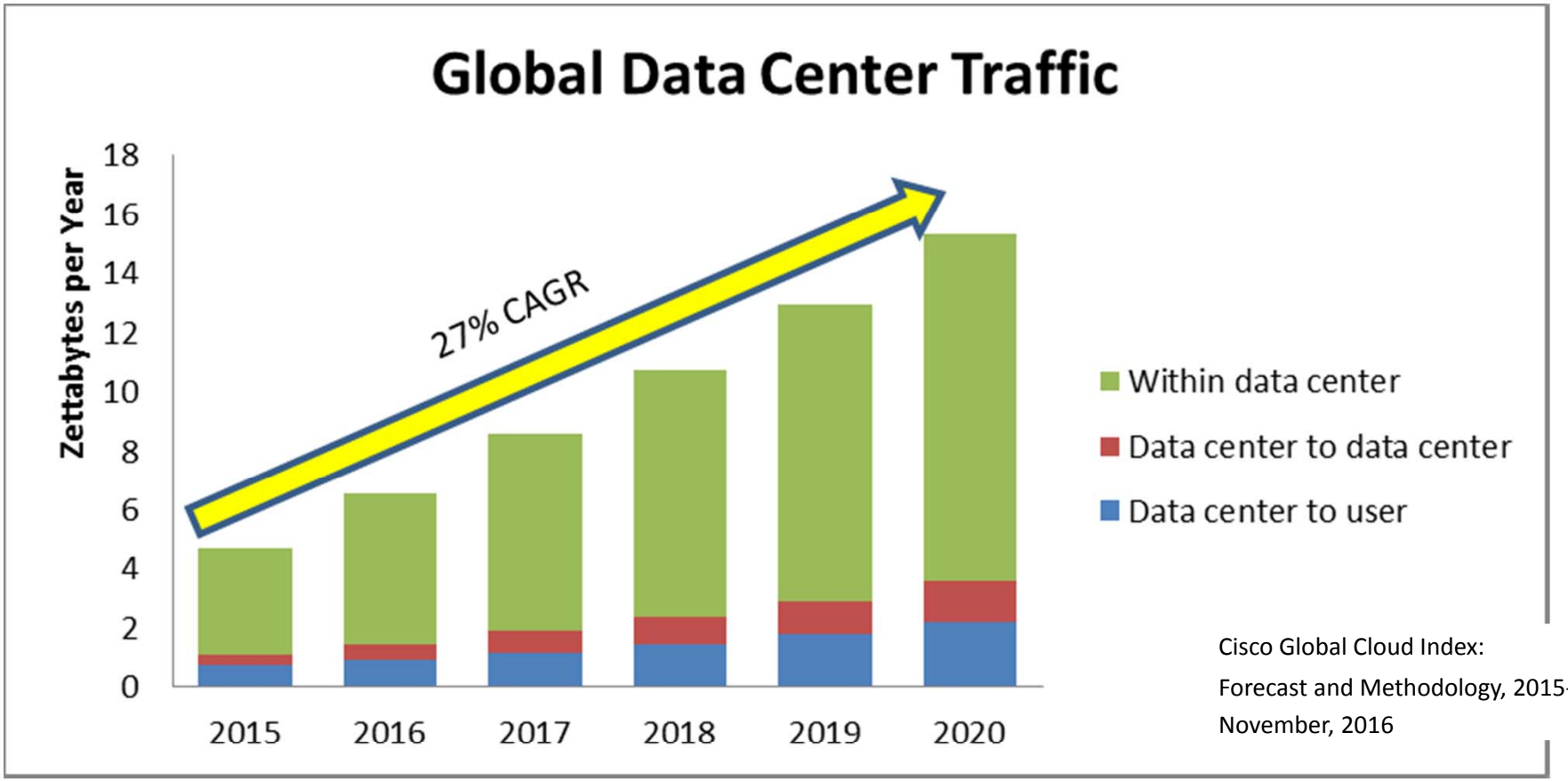
- Data Center Market Drivers
- Fiber Types
- Application Standards
- Next Generation Solutions
- Conclusions

Global Data Center Traffic By Destination in 2020



Source: Cisco Global Cloud Index, 2015–2020.

- Global data center traffic will reach 14.1 zettabytes in 2020, from 3.9 zettabytes in 2015
- Hyperscale data centers will account for 47% of all installed data center servers by 2020
- Hyperscale data centers account for 34% of total traffic within data centers in 2015 and will make up 53% by 2020



Cisco Global Cloud Index:
Forecast and Methodology, 2015-2020
November, 2016

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Two Basic Optical Fiber Types

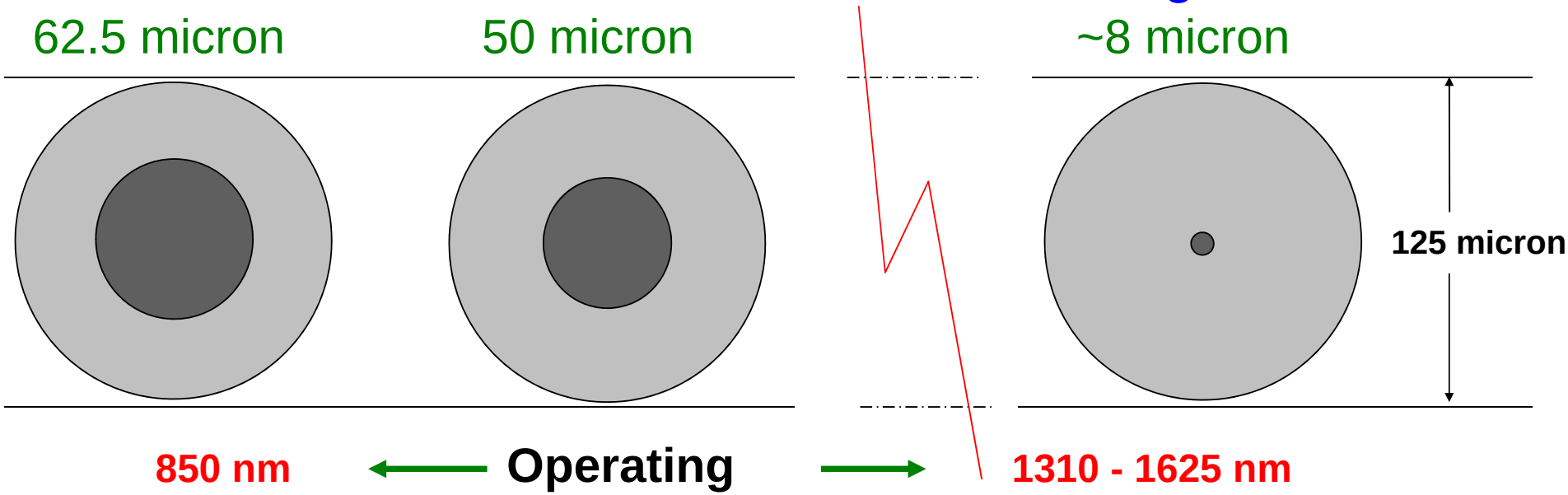
1. Multimode

62.5 micron

50 micron

2. Single-mode

~8 micron



850 nm & some 1300 nm

Operating Wavelengths

1310 - 1625 nm

Larger cores and lower wavelengths drive multimode system costs down

Multimode Fiber Types

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

	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)	
Fiber Type	**ISO/IEC 11801 (draft)**	**IEC 60793-2-10**	**TIA-568.3-D**	**TIA/EIA 492AAAx**	**ITU-T**	**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	1.5	1500	500	2000	---
50/125	OM4	A1a.3b[(3)]	TIA 492AAAD (OM4)	492AAAD	---	3.0	1.5	3500	500	4700	---
50/125	OM5 (draft)	A1a.4b[(3)] (draft)	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

ISO/IEC 11801 "Generic Cabling for Customer Premises"
IEC 60793-2-10 "Product Specifications - Sectional Specification for Category A1 Multimode Fibres"
TIA-568.3-D "Optical Fiber Cabling and Components Standard"
TIA/EIA-492AAAx "Detail Specification for… Class 1a Graded-Index Multimode Optical Fibers"
ITU-T G.651.1 "Characteristics of a 50/125 um Multimode Graded Index Optical Fibre Cable for the Optical Access Network"

Single-Mode Fiber Types

Fiber Type	Industry Standards				Attenuation Typical Cabled Max. (dB/km)		
	ISO/IEC 11801	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 G.652	"Characteristics of a single-mode optical fibre and cable"

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

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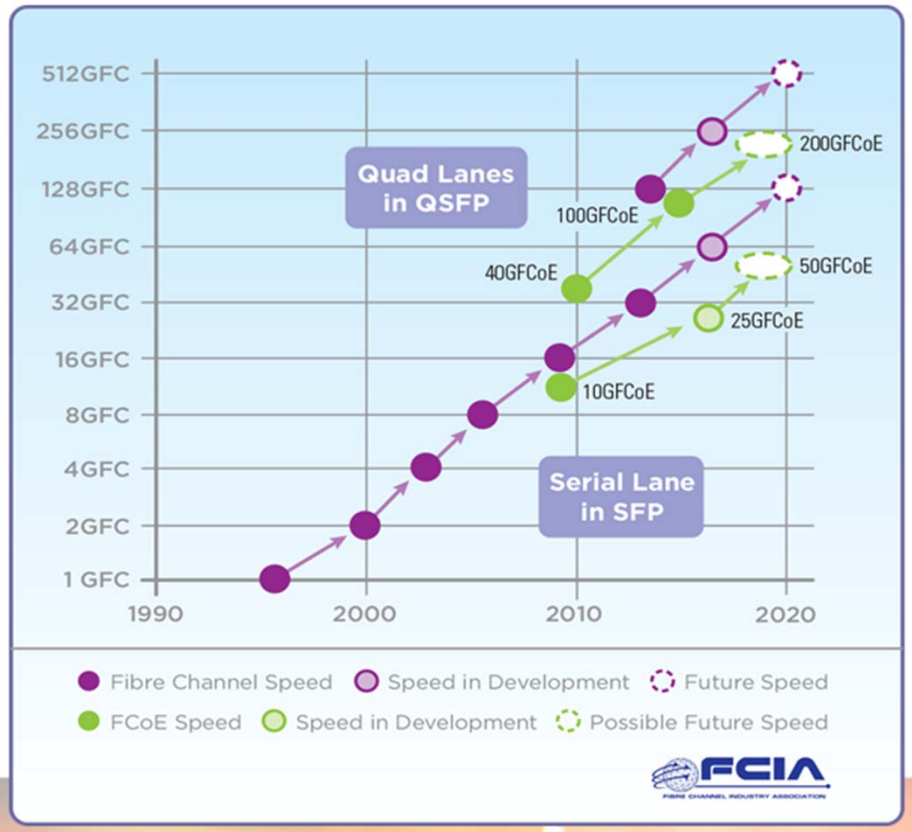
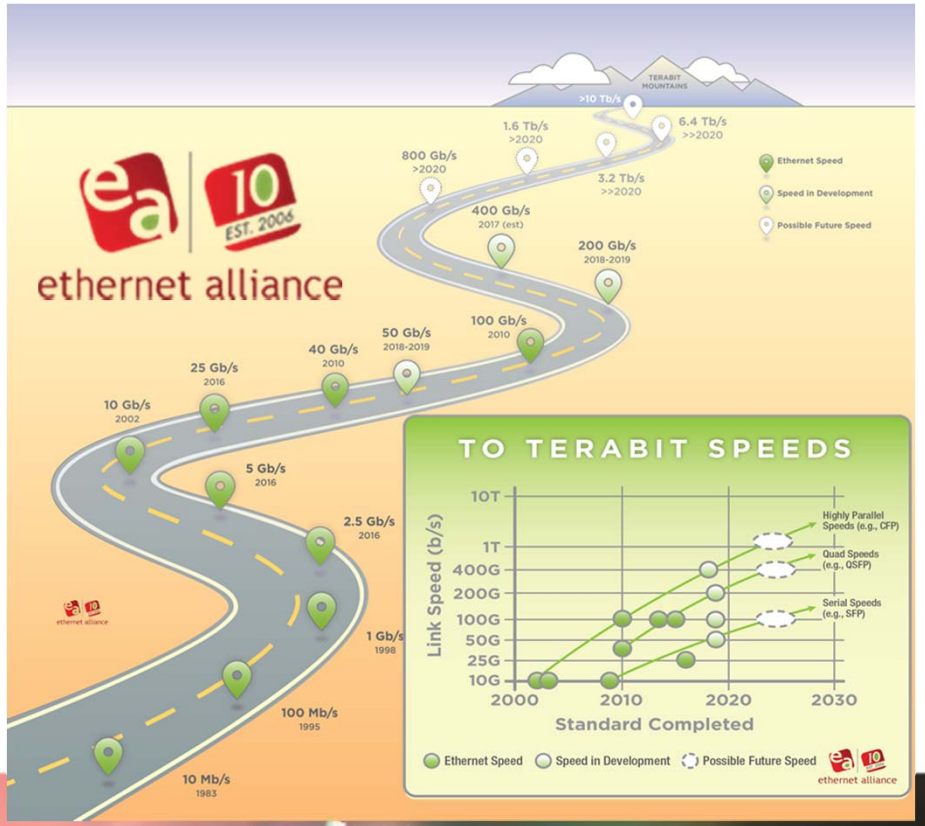
Evolution of Short Reach Applications





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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-SR4 (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

Published in 2010

*** non-standard solution**

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-SR4 (extended reach)*	200 m OM3 300 m OM4	8-f MMF (12-f MPO)	4x25G parallel NRZ 850 nm

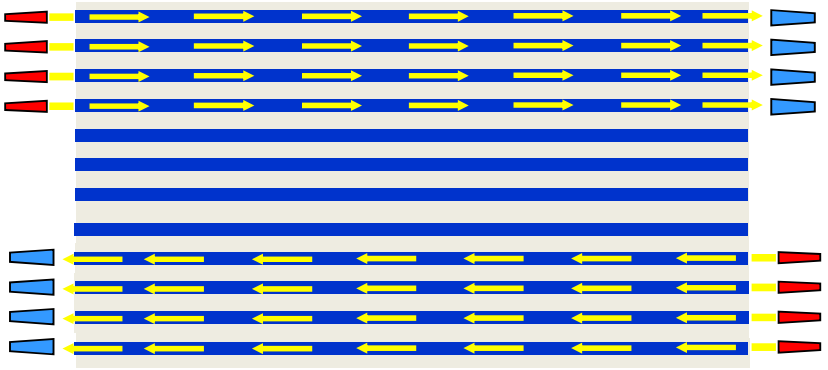
Published in 2015

*** non-standard solution**

High Speed Short Reach Technologies: Multiple Fiber Parallel Systems

NOW for 100G:

- One 12-fiber cable
  - 8 active fibers
- 12 Fiber MPO connector
- One wavelength per fiber
- 4 x 25 Gb/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

Latest Ethernet Developments

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

Publication expected in 2017

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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

Publication expected in 2017

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

Publication expected in 2018

IEEE 802.3 Industry Connections
New Ethernet Applications Ad Hoc
(IEEE802.3 NEA Ad Hoc)

- **Work underway to develop a Call For Interest (CFI) proposing, "Next Generation 400 and 200 Gb/s Ethernet PHYs over Fewer Multimode Fiber Pairs"**
  - Suggests the use of Short Wavelength Division Multiplexing (SWDM) technology to reduce multimode fiber counts for standards based 200 and 400Gb/s Ethernet

Technical options for Next-Gen MMF PMDs

Technology (per fiber)	1 fiber pair	1 fiber pair	4 fiber pairs	8 fiber pairs	16 fiber pairs
25G-λ NRZ	25G-SR		100G-SR4		400G-SR16
50G-λ PAM4	50G-SR	100G-SR2	200G-SR4		
2x50G-λ PAM4	100G-SR1.2	200G-SR2.2	**400G-SR4.2**	400G-SR8	
4x25G-λ NRZ	100G-SR1.4	200G-SR2.4	**400G-SR4.4**	**Technology options for 200 & 400 Gb/s links over fewer MMF fiber pairs**	
4x50G-λ PAM4	**200G-SR1.4**	**400G-SR2.4**	800G-SR4.4		

Existing IEEE standard

In progress in 802.3bs/cd

Multi-Wavelength Nomenclature

SRm.n **m = # fiber pairs**

n = # wavelengths

Source: "Next-gen 400 and 200 Gb/s PHYs over Fewer MMF Pairs" Call For Interest Consensus Presentation, Draft 0.3, IEEE 802.3 NEA Ad Hoc, 03-14-17

Multimode Summary

Speed	10G/λ, NRZ	20G/λ, NRZ	25G/λ, NRZ	50G/λ, PAM-4
10G	 802.3ae standard	N/A	N/A	N/A
25G	N/A	N/A	 802.3by standard	N/A
40G	 802.3ba standard  SWDM4	 SWDM2 (BiDi)	N/A	N/A
50G	N/A	N/A	N/A	 802.3cd proposal
100G	 802.3ba standard	N/A	 802.3bm standard	 SWDM2
		N/A	 SWDM4	 802.3cd proposal
200G	N/A	N/A	N/A	 802.3cd proposal
		N/A		 SWDM4
400G	N/A	N/A	 802.3bs proposal	 SWDM2
		N/A	 SWDM4	 SWDM8?

	Ethernet Standard
	Proposed Standard
	Proprietary Solution

Single-mode Summary

Speed	10G/λ, NRZ	25G/λ, NRZ	50G/λ, PAM-4	100G/λ, PAM-4
10G	802.3ae standard	N/A	N/A	N/A
25G	N/A	802.3cc proposal	N/A	N/A
40G	40G PSM4 802.3ba standard	N/A	N/A	N/A
50G	N/A	N/A	802.3cd proposal	N/A
100G	N/A	100G PSM4 802.3ba standard	802.3cd proposal	N/A
200G	N/A	N/A	802.3bs proposal 802.3bs proposal	N/A
400G	N/A	N/A	802.3bs proposal	802.3bs proposal

	Ethernet Standard
	Proposed Standard
	Proprietary Solution

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

64/256GFC – FC-PI-7

Variant	Link Distance	Fiber Count and Media Type	Technology
64GFC	100 m OM4/OM5	2-f MMF	Under Discussion Could be WDM w/ NRZ or PAM-4
64GFC	10 km?	2-f SMF	Under Discussion
256GFC	100 m	8-f MMF	Under Discussion PAM-4 or NRZ
256GFC	2 km?	2-f SMF	Under Discussion

Technical agreement expected in late 2017

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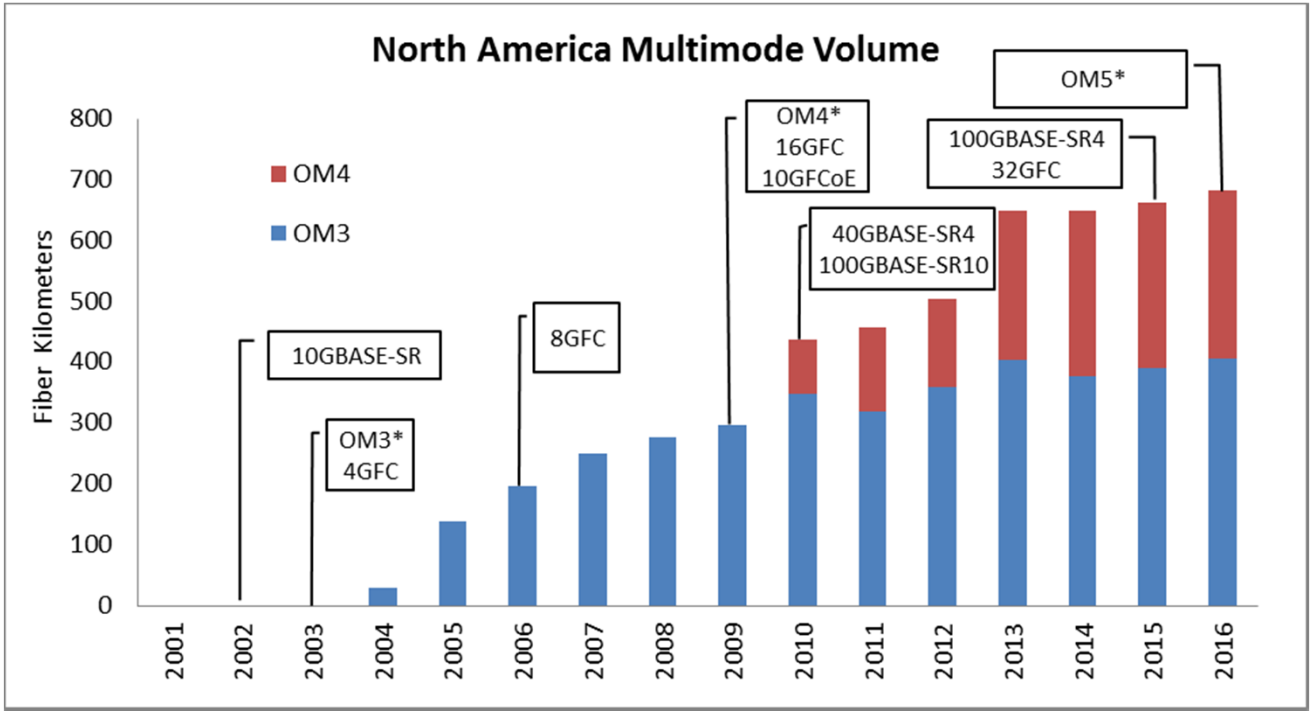
Next Generation Solutions

- **Short Wavelength Division Multiplexing (SWDM)**
- **Multilevel Signaling**

Why do we need a new multimode fiber? And why SWDM?

- Cannot continue to increase fibers as bandwidth increases
  - End user reluctant to run 2x16 – 32 fiber cables for a 400Gb/s
- SWDM allows multiple wavelengths to be used, reducing the number of fibers
- Utilizes same simplex LC and multi-fiber MPO connector technology
- Can provide duplex fiber 100Gb/s links
- Enables 400Gb/s transmission using 8-fiber technology, currently adopted in 40Gb/s links

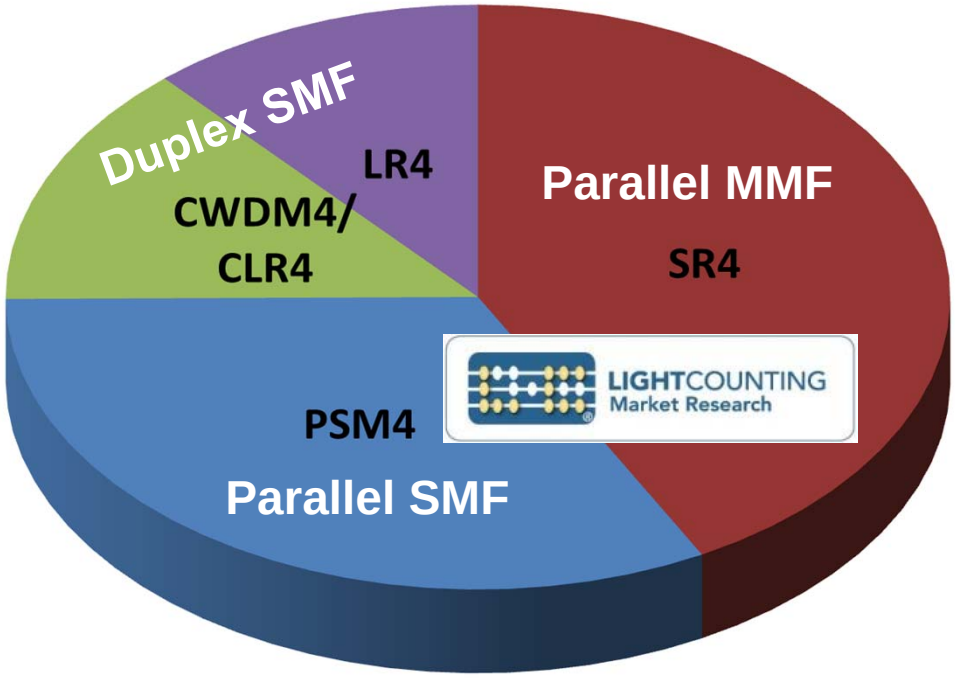
Continued Deployment & Growth of OM3/OM4 MMF
Continued Transition from OM3 to OM4



Source: Matthew Burroughs North America Multimode Reports

* Dates are ANSI/TIA standardization dates, not ISO/IEC

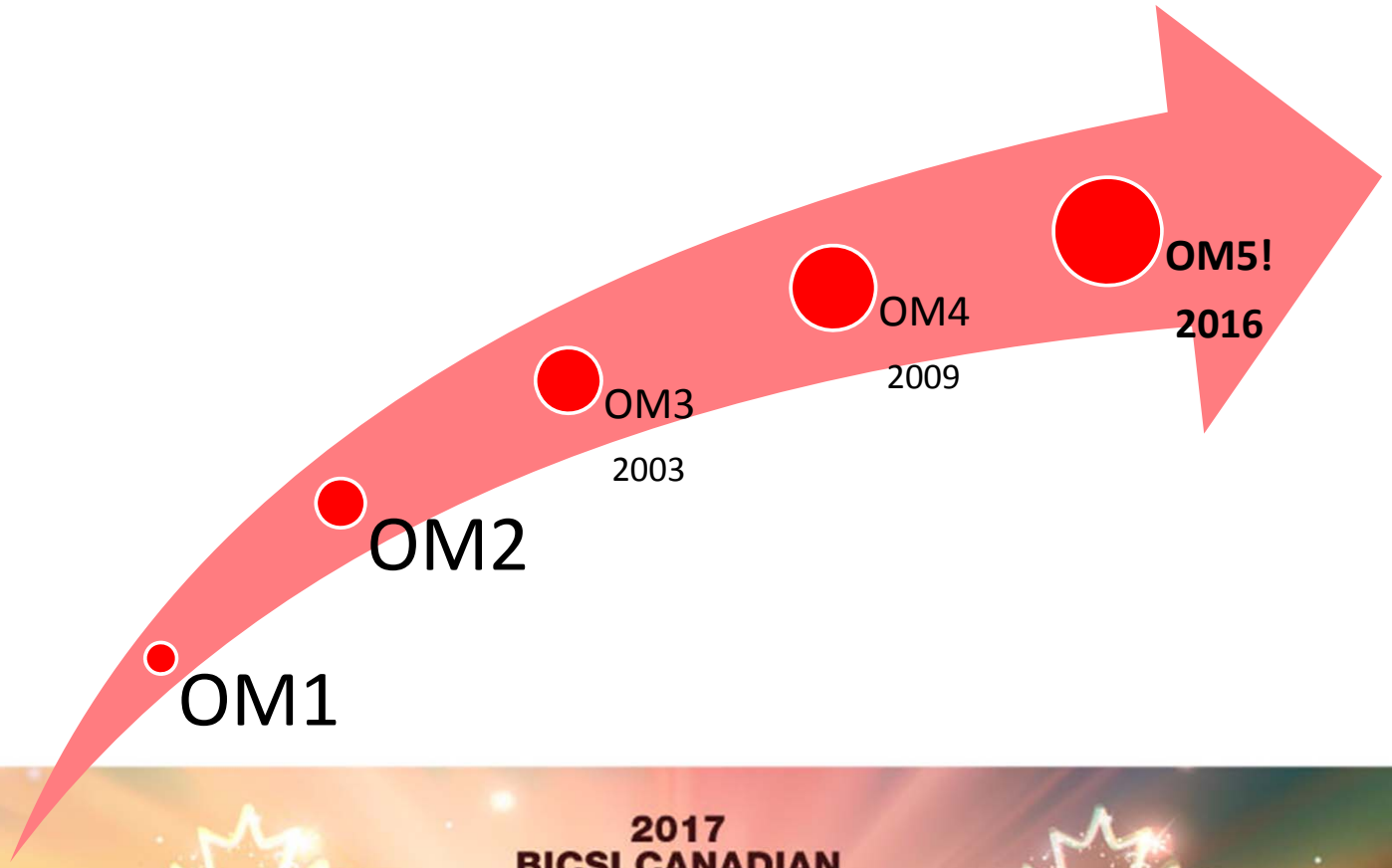
100GbE QSFP28 Consumption in 2016



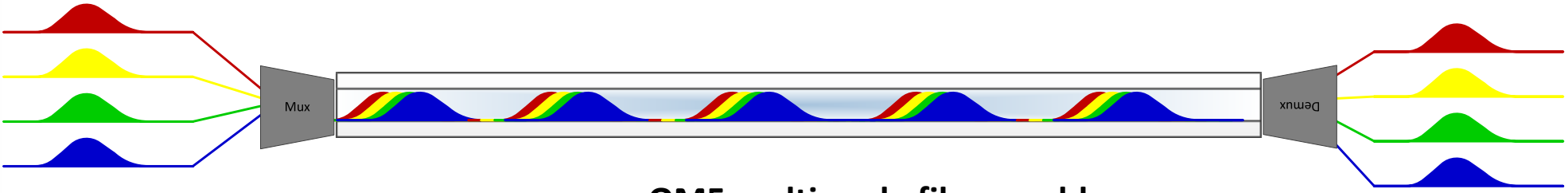
- Chart shows units shipped
- Short-reach SR4 modules had the greatest individual contribution to 2016 shipments of QSFP28 modules

Chart courtesy of Dale Murray, LightCounting

Multimode Fiber Evolution



What can you do with OM5 fiber?



OM5 multimode fiber enables
Short Wavelength Division Multiplexing (SWDM)
Multiple wavelengths (colors) on the same fiber
40/100/200? Gb/s

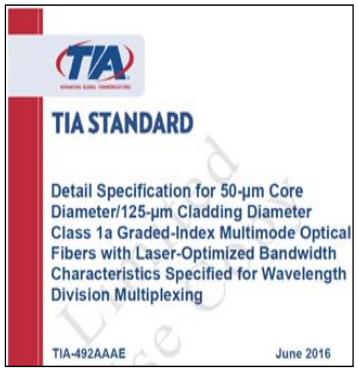
LC Duplex SWDM transceivers

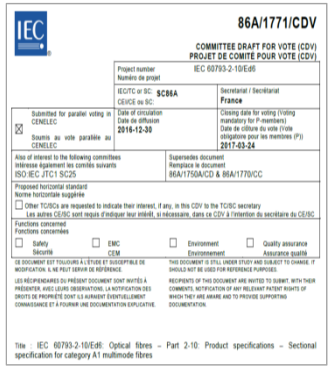
					Link Distance		
Speed	Vendor	Transceiver	Form Factor	λ	OM3	OM4	OM5
40Gb/s	FIT	BiDi	QSFP+	2	100	150	200
40Gb/s	Cisco/ Arista/ Brocade	BiDi	QSFP+	2	100	150	
40Gb/s	Finisar	SWDM4	QSFP+	4	240	350	440
100Gb/s	Finisar	SWDM4*	QSFP28	4	75	100	150

* Announced

Wideband Multimode OM5 Fiber Standards

- OM5 MMF extends the performance of OM4 at 850nm through 950nm
- Drop-in replacement for OM4 at 850nm. Fully backward-compatible with previous IEEE and Fiber Channel standards
- Accommodates up to four wavelengths on economical grid spacing
- Standards:
  - Fiber: TIA-492AAAE (2016), IEC 60793-2-10 ed. 6 (target 1Q17)
  - Structured Cable: ANSI/TIA-568.3-D (2016), ISO/IEC 11801 ed. 3 (target 2017)



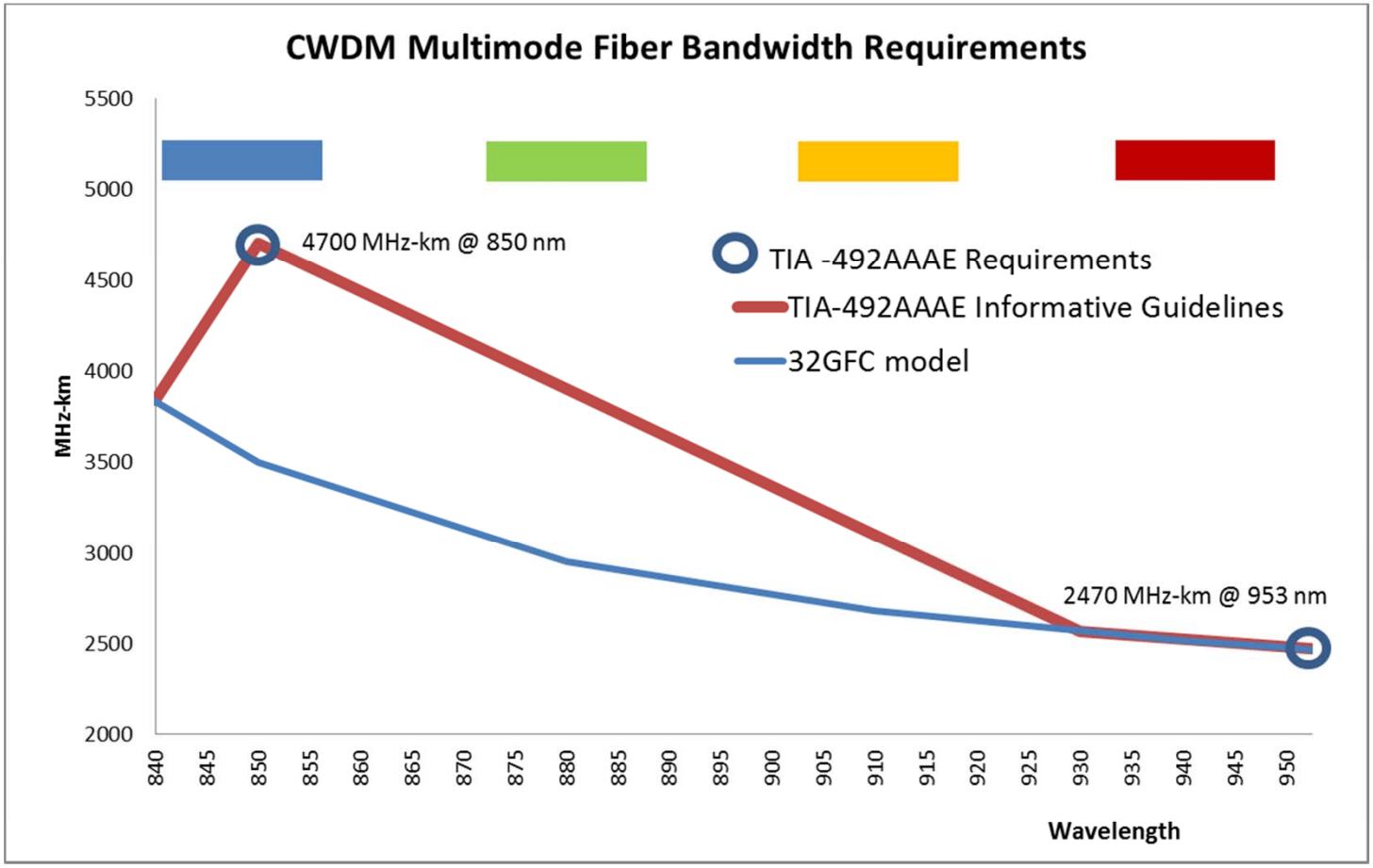


Fiber Standards

Cable Standards

Differences between OM4 and WideBand OM5 fiber

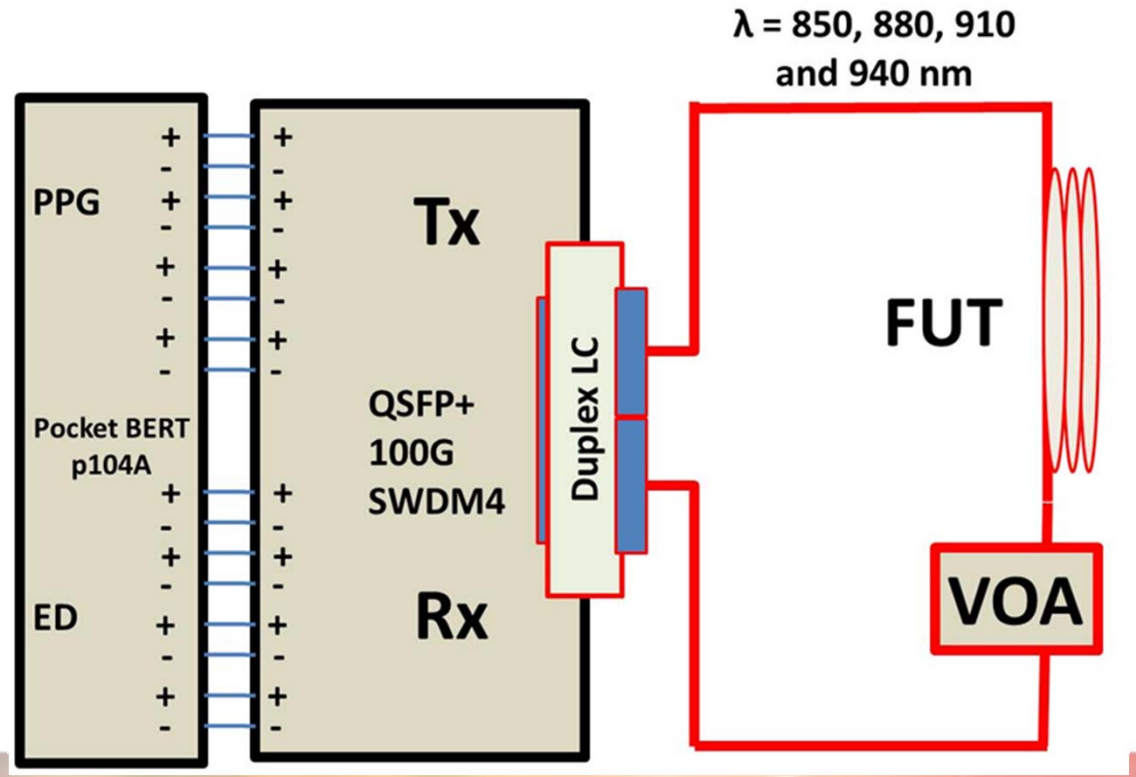
	OM4 Multimode Fiber	WideBand (OM5) Multimode Fiber
Zero Dispersion Wavelength	$1295 \le \lambda_o \le 1340$ nm	$1297 \le \lambda_o \le 1328$ nm
Zero Dispersion Slope	$S_0 \le 0.105$ ps/nm^2·km for $1295 \le \lambda_o \le 1310$ nm, and $\le 0.000375(1590-\lambda_o)$ ps/nm^2·km for $1310 \le \lambda_o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


CWDM Multimode Fiber Bandwidth Requirements
5500
5000
4500
4000
3500
3000
2500
2000
MHz-km
4700 MHz-km @ 850 nm
2470 MHz-km @ 953 nm
TIA -492AAAE Requirements
TIA-492AAAE Informative Guidelines
32GFC model
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 fiber field testing

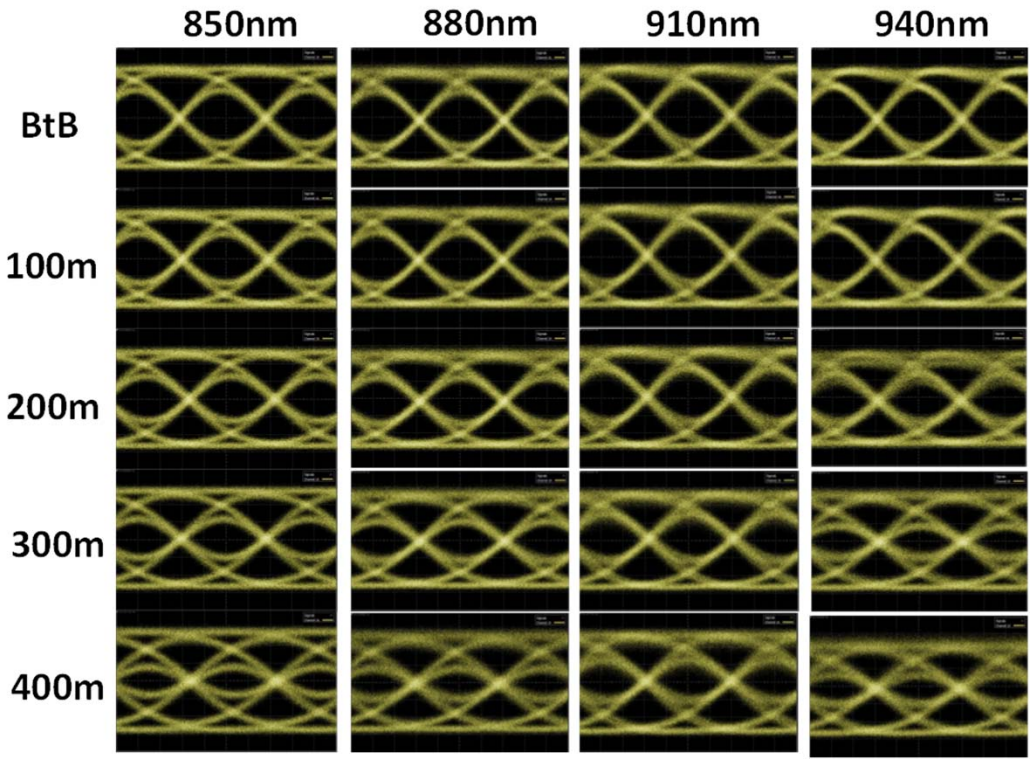
- **No additional field testing required for wideband fiber**
  - **953nm attenuation requirement**
    - If 850nm and 1300nm attenuation requirements are met, 953nm requirements are also met
  - **953nm bandwidth requirement**
    - Performance insured by DMD measured by fiber manufacturers
  - **Chromatic dispersion**
    - Performance insured by fiber manufacturers

4 x 25 G SWDM System Testing



- 4 channels run simultaneously
  - 4 x 25.78 Gbps
  - PRBS 31
  - 850, 880, 910, 940 nm
- LaserWave *FLEX* Wideband Fiber
  - 100, 200, 300, 400 m
  - LC termination
- External cooling with a fan
- Transmitter characterization
  - RMS spectral width <0.6nm
  - EF meet IEEE802.3bm spec

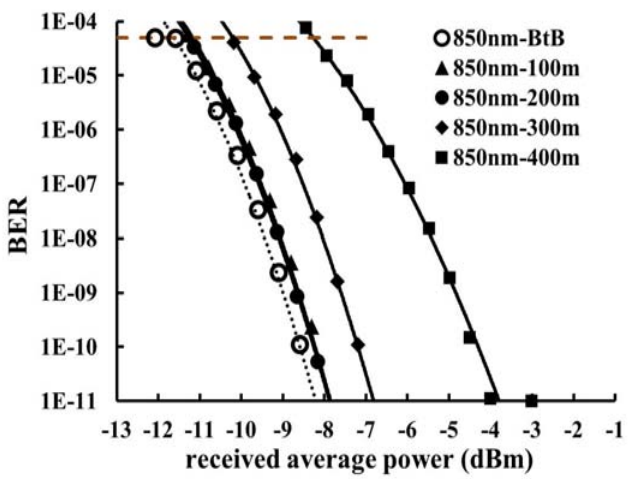
Optical Eyes: 100G SWDM over LaserWave *FLEX* Wideband Fiber

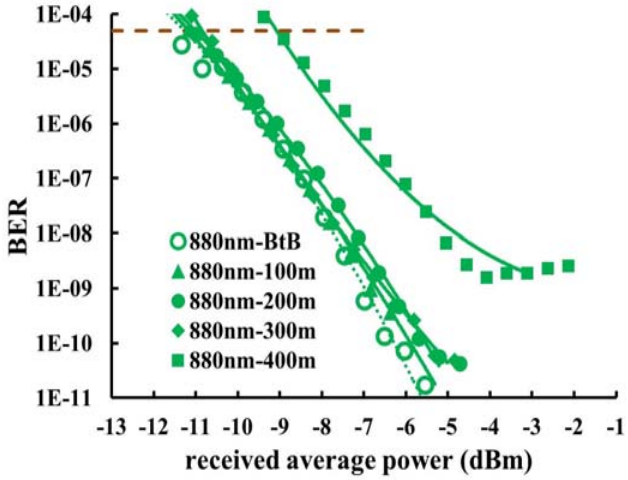


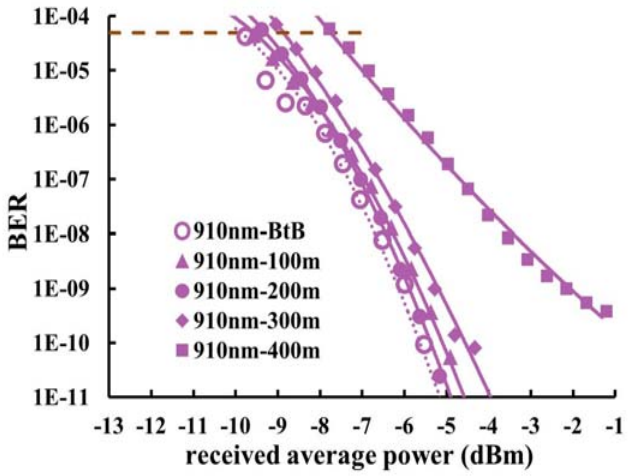
ISI increasing

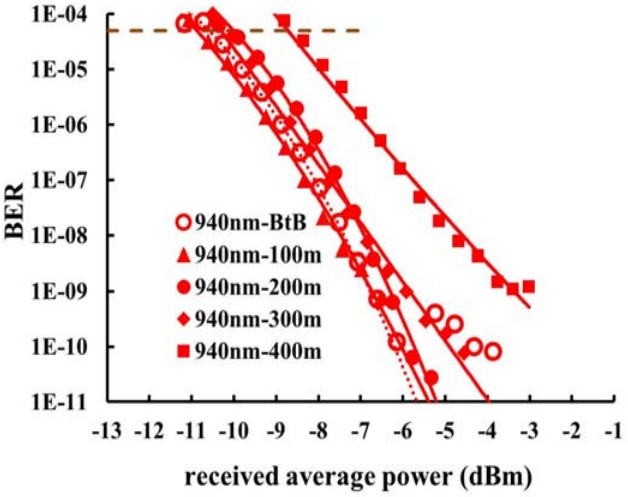
remain open

100G SWDM transmission over LaserWave *FLEX* Wideband Fiber







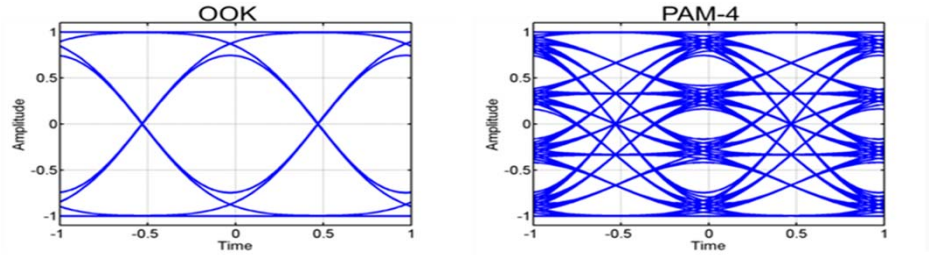


- **BER after 100 and 200m is barely increased from B2B results**
- **Pre-FEC BER : five orders better than 5×10^{-5} up to 300 m**

Multilevel Signaling

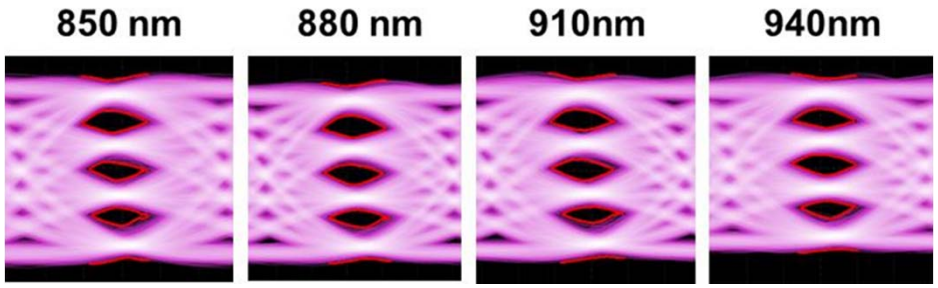
Multilevel signaling

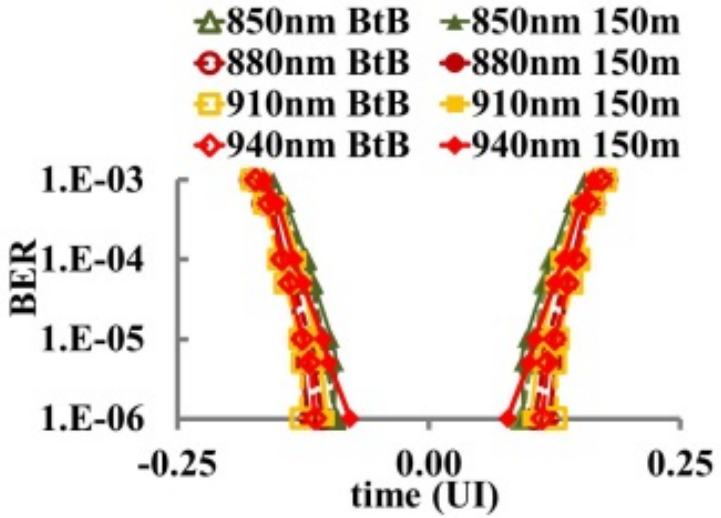
- PAM-4
  - Increases the bit rate 2x



- **Currently under discussion in IEEE and FC for next generation solutions**
  - Will leverage CWDM efforts to further expand fiber capacity
  - 50Gb/s lane rates
- **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 *FLEX* WideBand Fiber





- **Demonstrated capacity of 206 Gbps over a single multimode fiber!**

Agenda

- Data Center Market Drivers
- Fiber Types
- Application Standards
- Next Generation Solutions
- Conclusions

Conclusions

- Bandwidth demand continues to grow
- Application standards continue to increase data rates
- Multimode fiber continues to support ever increasing data rates
  - Wideband multimode fiber is standardized in TIA, and nearing conclusion in ISO/IEC
- Multilevel signaling work is underway
  - Path to 50G lanes