The Fabulous, Fast Moving, Fever Pitch, Forever Accelerating Fiber Frenzy

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Darryl Heckle - Corning
Tony Irujo - OFS
Robert Reid - Panduit

Fiber Optics Technology Consortium

Overview:

- Part of the Telecommunications Industry Association (www.tiaonline.org)Until 2013, we had been known as the Fiber Optics LAN Section (FOLS). Our new name was chosen to reflect our expanding charter.
- Formed 23 years ago
- Mission: to educate users about the benefits of deploying fiber in customer-owned networks
- FOTC provides vendor-neutral information

Fiber Optics Technology Consortium

Current Members

- AFL
- CommScope
- Corning
- EXFO
- Fluke Networks
- General Cable
- OFS

Current Members

- Legrand
- Panduit
- Sumitomo Electric Lightwave
- Superior Essex
- The Siemon Company
- Viavi

Fiber Optics Technology Consortium

- Maintain a website with Fiber FAQs, White Papers and other resources – www.tiafotc.org.
- Developed and maintain a free Cost Model that allows users to compare installed first costs of several architectures.
- Host a webinar series throughout the year with all webinars available on demand.
- Speak at industry conferences like BICSI
- Contribute to industry publications – Like BICSI News.
- Conduct market research – like the surveys today

Fiber Optics Technology Consortium

- Recent Webinars Available on Demand
  - Keeping up with High Speed Migration in the Data Center
  - Data Center Design, Planning & Upcoming Changes to TIA-942
  - Best Practices for Achieving Tier 1 Fiber Certification

- Visit www.tiafotc.org or our channel on BrightTalk

- Webinars are eligible for CEC credit for up to two years after they are first broadcast. Email liz@goldsmithpr.com if you have completed a webinar and want to receive your CEC.

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Any product(s) identified or identifiable via a trade name or otherwise in this presentation as a product(s) supplied by a particular supplier(s) is provided for the convenience of users of this presentation and does not constitute an endorsement of any kind by TIA of the product(s) named. This information may be provided as an example of suitable product(s) available commercially. Equivalent product(s) may be used if they can be shown to lead to the same results.

TIA Standards Update

Cindy Montstream, EE, RCDD/NTS, CPLP

Director of Technology Excellence
Data Communications Division, Legrand

Chair, TIA TR-42.3
Vice Chair, TIA TR-42.6, 42.16
FOTC Standards Chair

TIA Standards Update

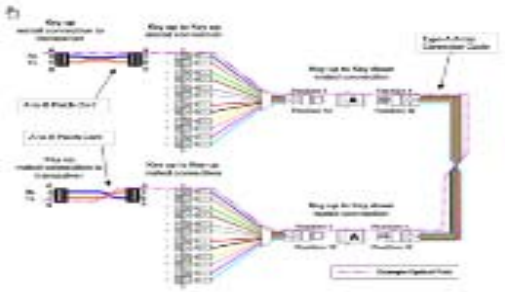
TR-42 | TELECOMMUNICATIONS CABLING SYSTEMS

- Develops standards for telecommunications cabling infrastructure
- Standards are grouped into 3 categories: Common, Premises and Cabling & Components
- Standards cover many different premises, i.e. data center, commercial building, residential, healthcare facility, education facility, etc.

Optical Fiber Cabling Components

ANSI/TIA-568.3-D

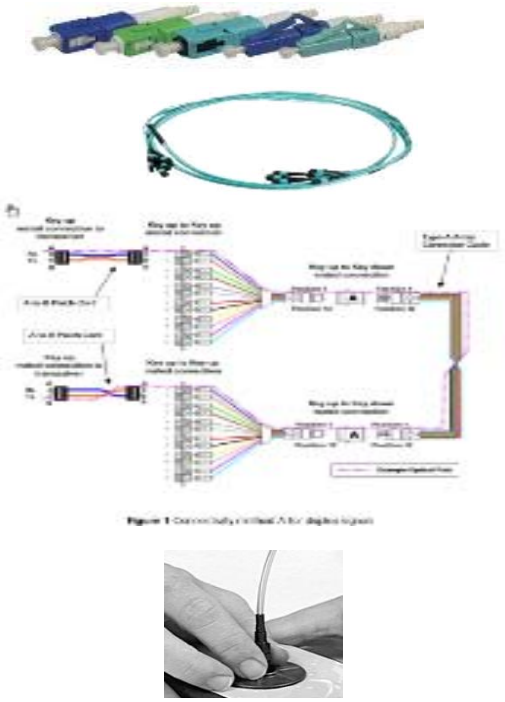
- Now components & cabling (testing, polarity, etc.)
  - Polarity from TIA-568.0
  - Testing from TIA-568.0
  - Passive optical network component specs
- Splitters will be part of budget
- Specifies encircle flux launch conditions for testing MMF @ 850 nm
  - Eliminates testing @ 1300 nm
- Raises min. return loss of SM connections & splices from 26 dB to 35 dB



Optical Fiber Cabling Components

ANSI/TIA-568.3-D continued….

- Lowers OM3 & OM4 attenuation @ 850nm to 3.0 dB/km
- Accounts for insertion loss of reference-grade test conditions
- Demotes OM1, OM2 & OS1 to not-recommended
- Adds specification for wideband multimode fiber
- Adds specification for OSP microduct cable
- Published 09/2016

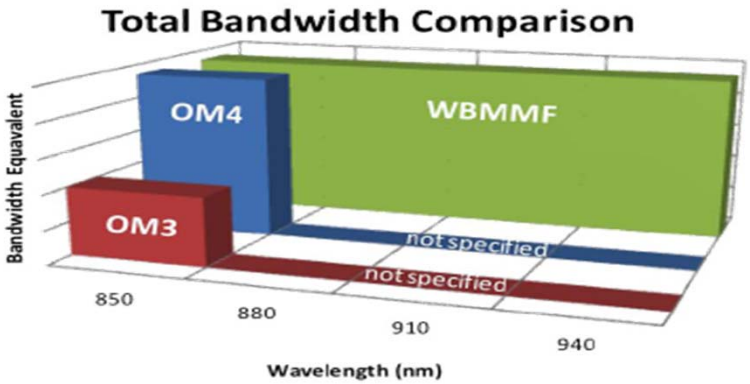


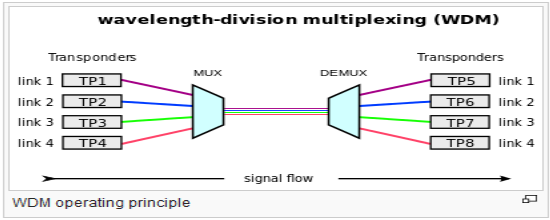
New fiber type

OM5: Wide Band Multimode Fiber

ANSI/TIA-492AAAE
Wide Band Multimode (WBMMF)

- 50µ Laser Optimized Multimode Fiber
  - Use cost effective MM VCSEL technology
- Optimized to support at least 4 wavelengths
- OM5 designation
- Backwards compatible
  - Continue to support legacy 850nm OM4 applications
- No additional field testing required
- Field polished the same way as any other MMF
- Published 06/2016

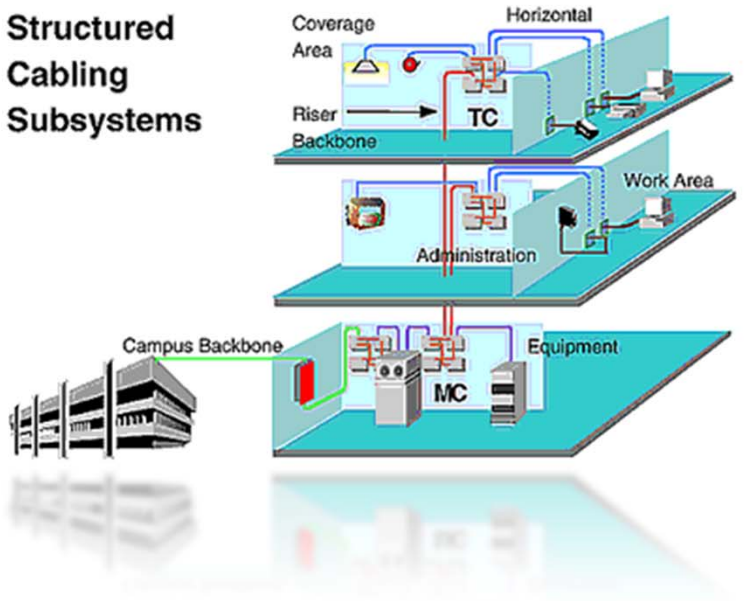




Generic Telecommunications Cabling

Work Just Competed:

- 568.0-D Addendum 1 (ANSI/TIA-568.0-D-1)
  - Significant fiber-related changes:
    - Recognized fiber now stated as --multimode optical fiber cabling (ANSI/TIA-568.3-D) 2-fiber (or higher fiber count); (updated reference & recommendation of OM3 or higher
    - OM5 added to application MM fiber table
    - Approved for Publication



Healthcare

Work Just Competed:

TIA-1179-A (ANSI/TIA-1179-A)

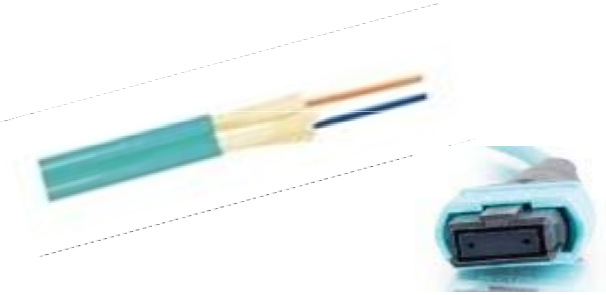
- Significant fiber-related changes
  - References were updated
  - OM4 is minimum MMF recommended
  - Minimum two fibers required for fiber backbone cabling
  - Array connectors now permitted in work area
  - MUTOA & Consolidation Points may be used as additional network elements
  - Approved for Publication

Data Center

Work Just Competed:

TIA-942-B (ANSI/TIA-942-B)

- Significant fiber-related changes:
  - Added MPO-16, MPO-32 (ANSI/TIA-604-18) & MPO-24 (ANSI/TIA-604-5)
  - Added wideband laser-optimized 50/125 um multimode (OM5)
  - Added recommendations for fiber in non-continuous pathways that could cause micro bends
  - Recommends pre-terminated cabling to reduce installation time & improve consistency & quality of terminations.



Data Center

Work Just Completed:

TIA-942-B (ANSI/TIA-942-B)

- Other significant technical changes:
  - Recommends that cabinets be at least 1200 mm (48”) deep & consider cabinets wider than 600 mm (24”).
  - Recommends considering need for proper labeling, cable routing, cable management, and ability to insert and remove cords without disrupting existing or adjacent connections.
  - Maximum cable lengths for direct attach cabling in EDAs reduced from 10 m (33 ft.) to 7 m (23 ft.).
    - Direct attach cabling between rows is not recommended.
- Approved for Publication

Commercial Building Telecommunications Cabling

Work In Progress:

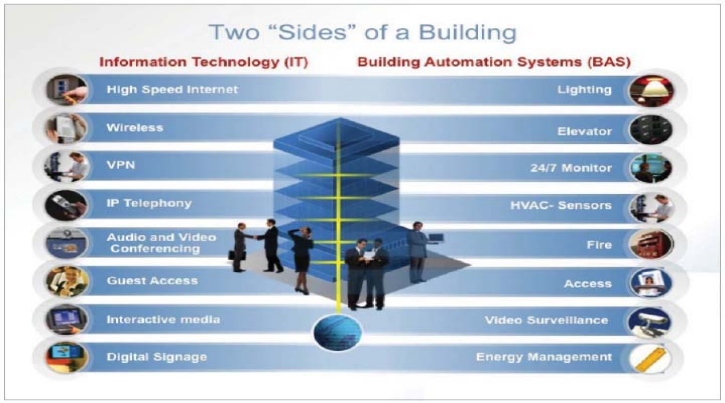
TIA 568.1-D Addendum 1 (ANSI/TIA-568.1-D-1)

- Significant fiber-related changes:
  - Backbone & horizontal recognize OM5
    - multimode optical fiber cabling, 2-fiber (or higher) fiber count; OM4 or OM5 wideband laser-optimized recommended

      NOTE – At the time of publication there were no standards-based applications specified for the 953 nm wavelength of OM5 wideband laser-optimized multimode cable.

- Mock ballot

Intelligent Building Systems



Work in Progress:

TIA-862-B Addendum 1 (ANSI/TIA-862-B-1)

- Significant fiber-related changes
  - Cabling Subsystems 1, 2, & 3
    - optical fiber cabling in compliance with ANSI/TIA-568.3-D, two fibers minimum

      NOTE – At the time of publication there were no standards-based applications specified for the 953 nm wavelength of OM5 wideband laser-optimized multimode cable.

  - Default Ballot

Education

Work in Progress:

TIA-4966 Addendum 1 (ANSI/TIA-4966-1)

- Significant fiber-related changes
  - MMF & SMF cabling compliant with ANSI/TIA-568.3-D, 2-fiber (or higher) fiber count

    NOTES for MMF:

    1. OM4 or OM5 wideband MMF recommended for new installations.
    2. At the time of publication there were no standards-based applications specified for the 953 nm wavelength of OM5 wideband laser-optimized multimode cable.
  - Default Ballot

Optical Fibers and Cables

Work in progress:

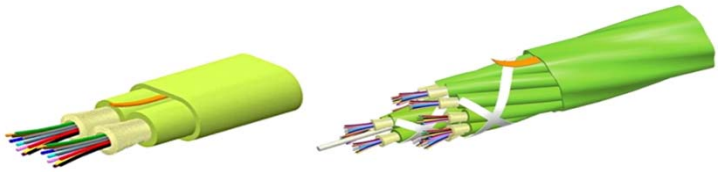
Revising TIA-598-D Addendum 1 & 2

- Addendum 1: Specs for colors 13-16
  - TG formed for round robin on color measurement for colors 13-16;
  - 2nd industry ballot (ANSI/TIA-598-D-1)
- Addendum 2: Jacket color for WBMMF
  - Approval of Lime for jacket color for OM5 fiber applications.
  - 1st Committee ballot (ANSI/TIA-598-D-2)

ANSI/TIA-PN-598-D-1 (to be ANSI/TIA-598-D-1)

Table 1 - Individual fiber, unit, and group identification

Position #	Base color/tracer per TIA	Abbreviation/print legend
1	Blue	1 or BL or 1-BL
2	Orange	2 or OR or 2-OR
3	Green	3 or GR or 3-GR
4	Brown	4 or BR or 4-BR
5	Slate	5 or SL or 5-SL
6	White	6 or WH or 6-WH
7	Red	7 or RD or 7-RD
8	Black	8 or BK or 8-BK
9	Yellow	9 or YL or 9-YL
10	Violet	10 or VI or 10-VI
11	Rose	11 or RS or 11-RS
12	Aqua	12 or AQ or 12-AQ
13	Lime	13 or LM or 13-LM
14	Tan	14 or TN or 14-TN
15	Olive	15 or OL or 15-OL
16	Magenta	16 or MG or 16-MG
17	Blue with Black Tracer	17 or D/BL or 17-D/BL[a]
18	Orange with Black Tracer	18 or D/OR or 18-D/OR
19	Green with Black Tracer	19 or D/GR or 19-D/GR
20	Brown with Black Tracer	20 or D/BR or 20-D/BR
21	Slate with Black Tracer	21 or D/SL or 21-D/SL



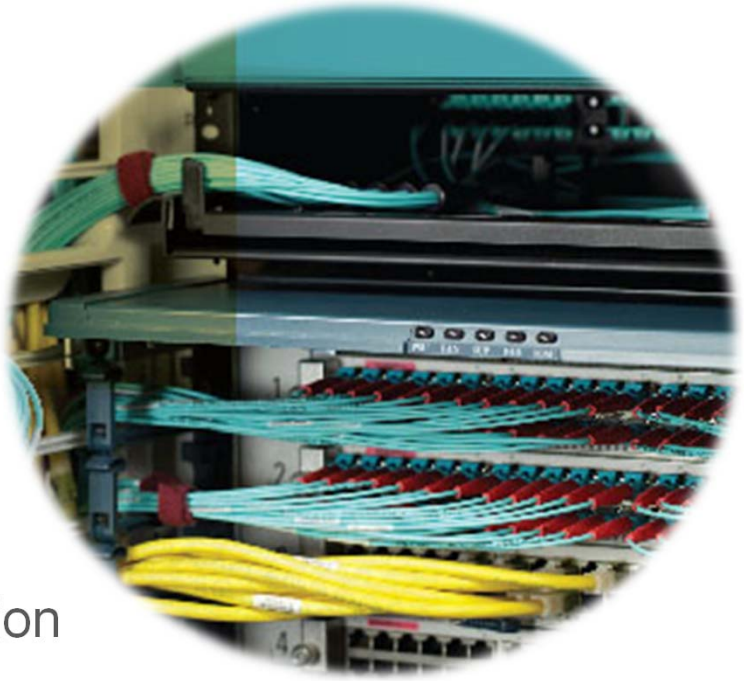
Optical Fiber Systems

New project:

TIA-568.3-D Addendum 1

Scope:

- Use of OM5 name
- Use of OS1a name
- Color for OM5 connecting hardware
- Connecting hardware color definitions
- Reference-grade to standard-grade loss allocation
- MPO testing



Residential Telecommunications Cabling & OSP

New Work:

- ANSI/TIA-570-C (Residential)
  - Submitted for 2nd industry ballot

- ANSI/TIA-758-B (OSP)
  - Project request to start C revision approved
  - 1st industry ballot based on editors schedule

Additional Information Available

FOTC Website

Summary of current TIA standards

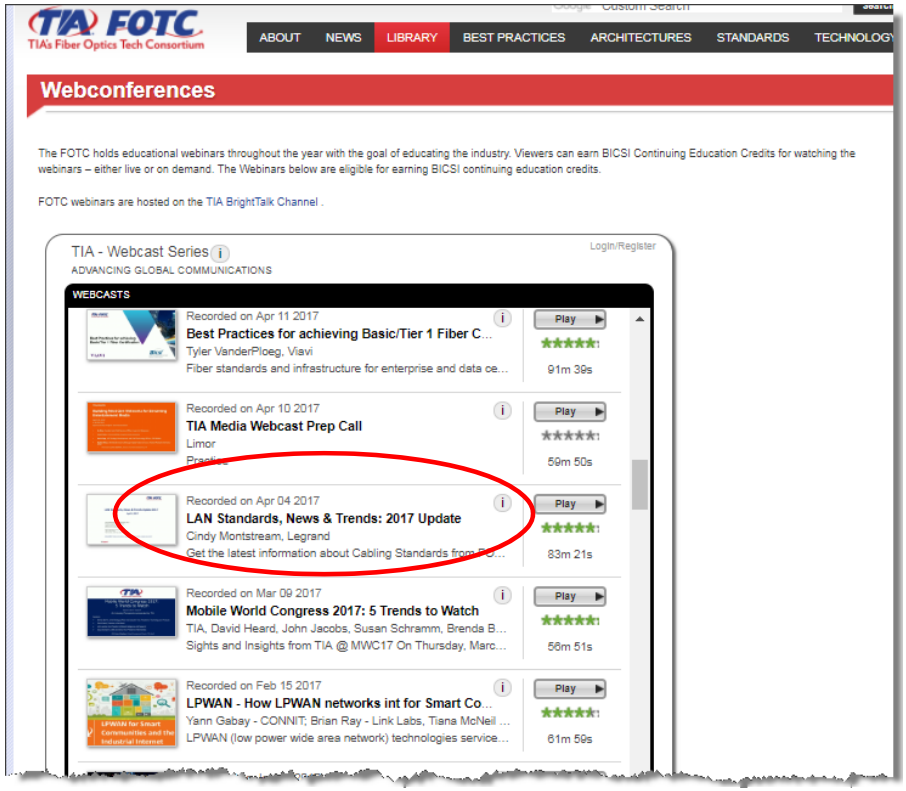
http://www.tiafotc.org

ANSI/TIA-568.0-D	GENERIC TELECOMMUNICATIONS CABLING FOR CUSTOMER PREMISES	09/14/15
ANSI/TIA-568.1-D	COMMERCIAL BUILDING TELECOMMUNICATIONS INFRASTRUCTURE STANDARD	09/09/15
*ANSI/TIA-568-C.2	BALANCED TWISTED-PAIR TELECOMMUNICATIONS CABLING AND COMPONENTS STANDARDS	04/2010
ANSI/TIA-568-C.2-1 (category 8 Addendum)	BALANCED TWISTED-PAIR TELECOMMUNICATIONS CABLING AND COMPONENTS STANDARD, ADDENDUM 1: SPECIFICATIONS FOR 100Ω CATEGORY 8 CABLING	06/30/16
ANSI/TIA-568.3-D	OPTICAL FIBER CABLING COMPONENTS STANDARD	09/16
ANSI/TIA-568-C.4	BROADBAND COAXIAL CABLING AND COMPONENTS STANDARD	7/11/11
ANSI/TIA-569-D	TELECOMMUNICATIONS PATHWAYS AND SPACES	11/19/15
ANSI/TIA-569-D-1	TELECOMMUNICATIONS PATHWAYS AND SPACES-ADDENDUM 1, REVISED TEMPERATURE AND HUMIDITY REQUIREMENTS FOR TELECOMMUNICATIONS SPACES	10/21/16
*ANSI/TIA-570-C	RESIDENTIAL TELECOMMUNICATIONS INFRASTRUCTURE STANDARD	08/16/12
ANSI/TIA-604-18	FOCIS 18 Fiber Optic Connector Intermateability Standard- Type MPO- 16	11/23/2015
*ANSI/TIA-606-B	ADMINISTRATION STANDARD FOR TELECOMMUNICATIONS INFRASTRUCTURE	6/22/12
TIA-606-B-1 (Addendum to TIA-606-B)	ADMINISTRATION STANDARD FOR TELECOMMUNICATIONS INFRASTRUCTURE ADDENDUM 1- AUTOMATED INFRASTRUCTURE	12/23/2015

FOTC Website

LAN Standards, News & Trends 2017

- http://www.tiafotc.org
- Library >Webconferences



IEEE and Fiber Channel Update

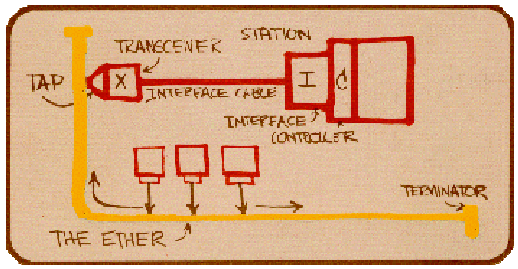
Darryl Heckle
Global Product Line Manager, Multimode Fiber
Corning Incorporated

Agenda

- IEEE
- Fiber Channel
- Future developments

IEEE Ethernet Standards

IEEE – what is it?

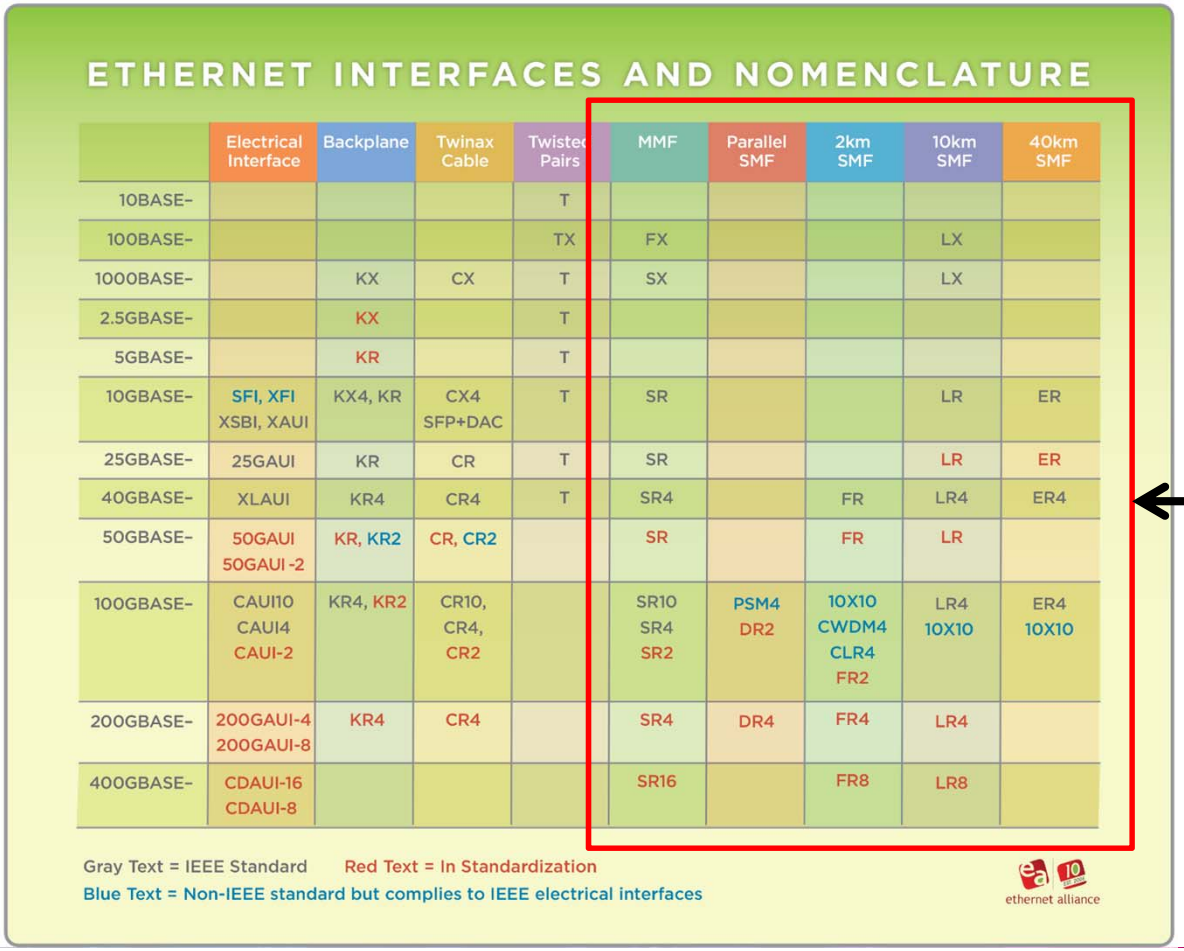


- For fiber, focus is on IEEE 802.3 – Ethernet Working Group
  - Develops standards for Ethernet networks
  - Working groups draft standards that are then presented to larger organization for approval
  - Includes all forms of physical transmission (copper, single mode fiber, multimode fiber)
  - Note that IEEE also covers wireless under other working groups

Ethernet Alliance

- Global consortium that promotes the use of Ethernet
- Relies on IEEE for standards definition
- Publishes roadmaps for Ethernet speeds

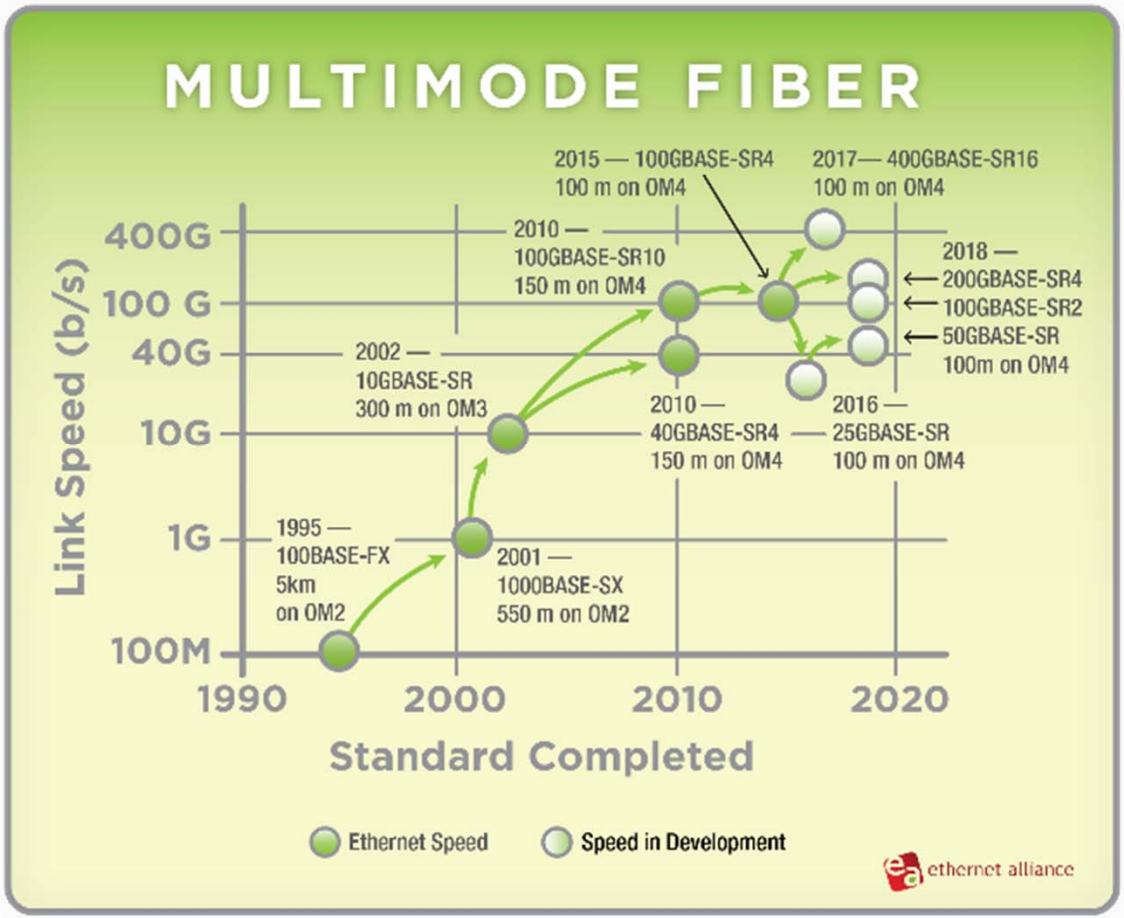
Ethernet Nomenclature



- Number indicates network speed
- i.e. 40G = 40 Gb/s

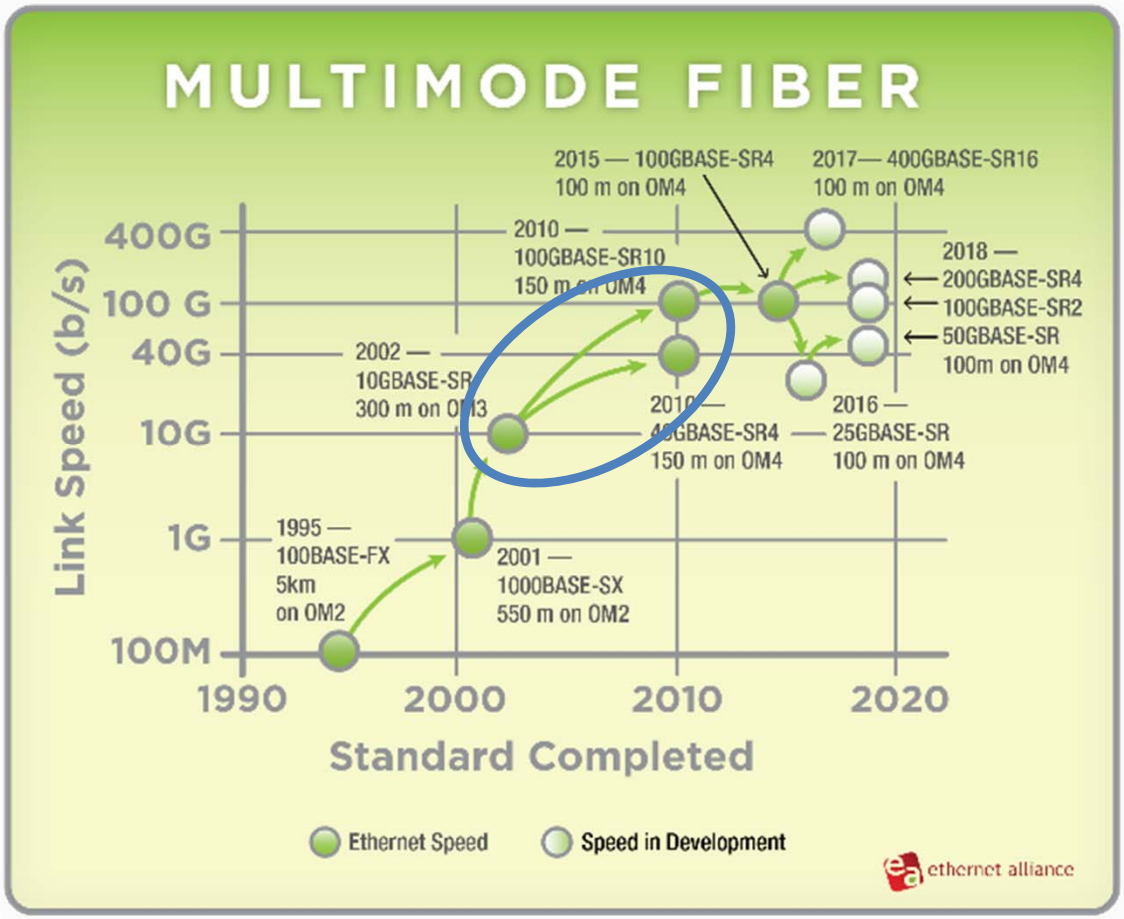
← Focus of this presentation

Multimode Fiber Roadmap



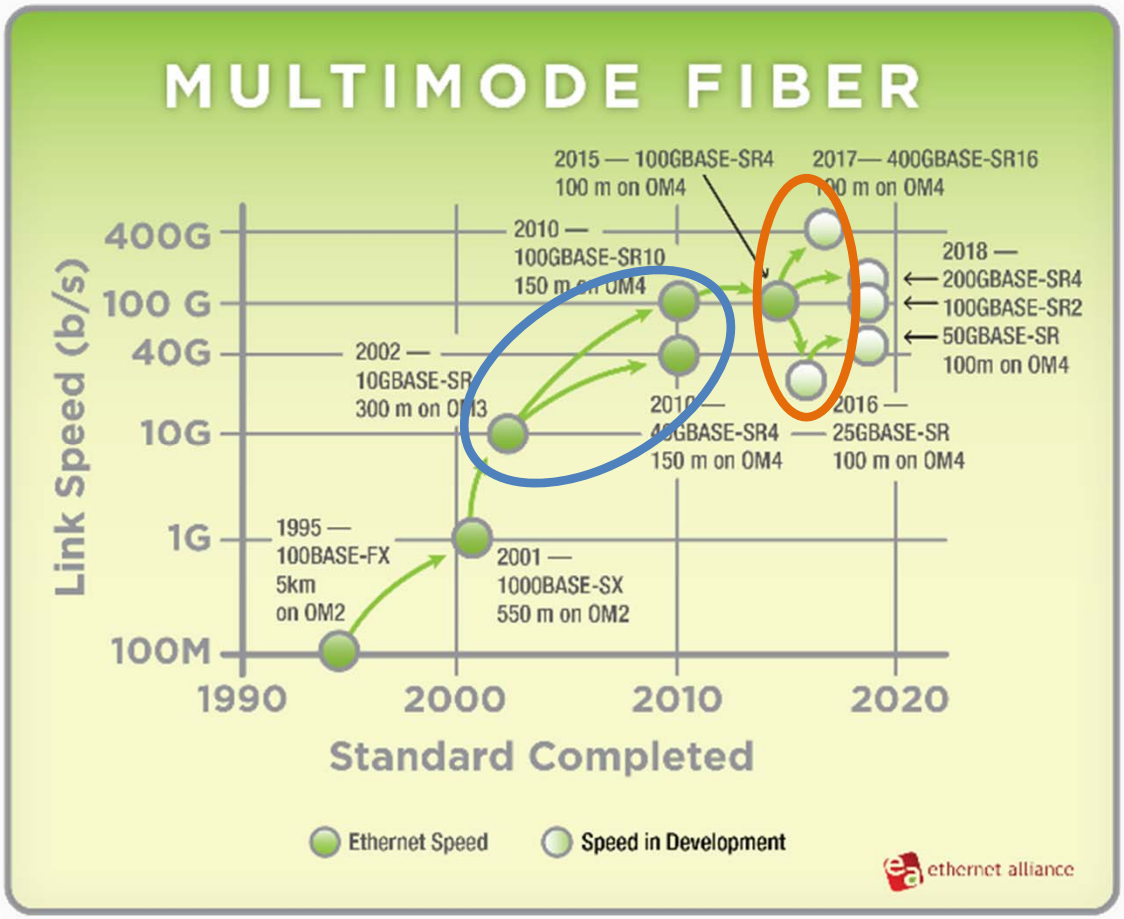
- Shows evolution of IEEE Ethernet speeds over MMF

Multimode Fiber Roadmap



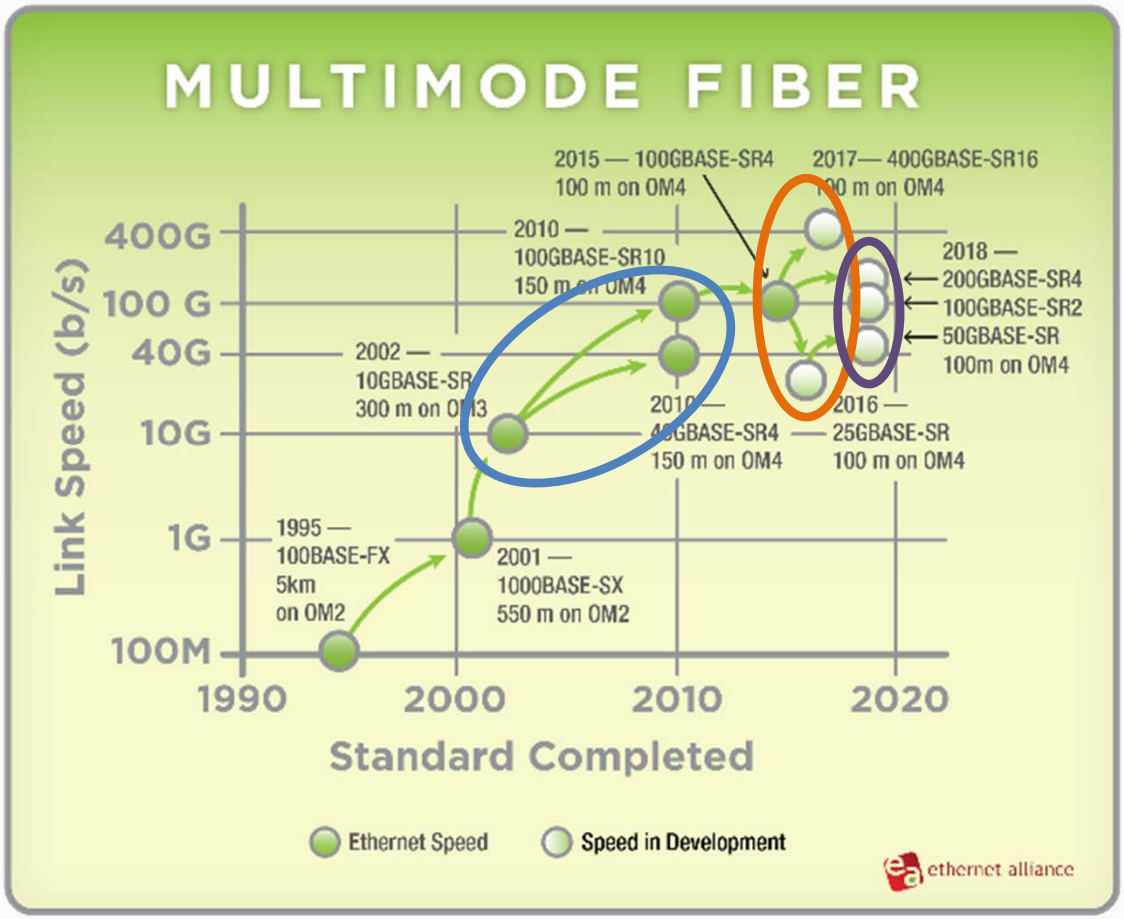
- 10G lanes:
  - 10G Base-SR
  - 40G Base-SR4
    - 4x10G lanes
  - 100G Base-SR10
    - 10x10G lanes

Multimode Fiber Roadmap



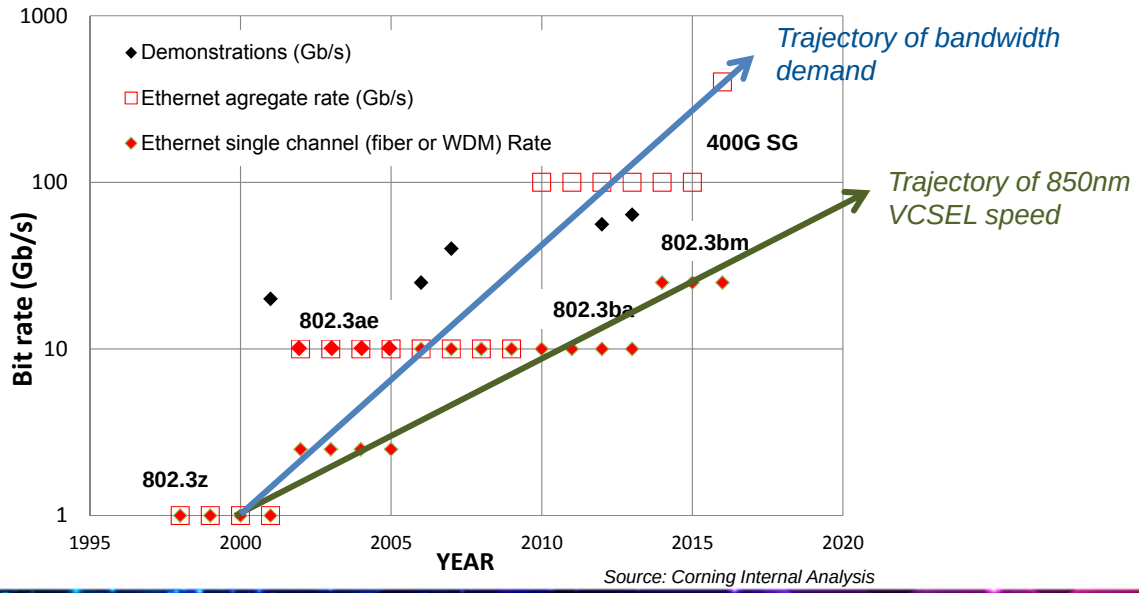
- 25G lanes:
  - 25G Base-SR
  - 100G Base-SR4
    - 4x25G lanes
  - 400G Base-SR16
    - 16x25G lanes

Multimode Fiber Roadmap



- 50G lanes:
  - 50G Base-SR
  - 100G Base-SR2
    - 2x50G lanes
  - 200G Base-SR4
    - 4x50G lanes

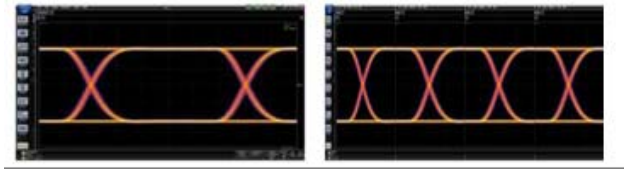
Multimode Fiber Roadmap - future



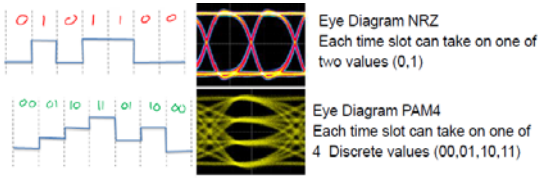
Source: Corning Internal Analysis

- Bandwidth demands are advancing faster than VCSEL speeds

Paths to Higher Data Rates



Increase baud rate
1G → 10G → 25G



Increase Modulation format
NRZ → PAM4

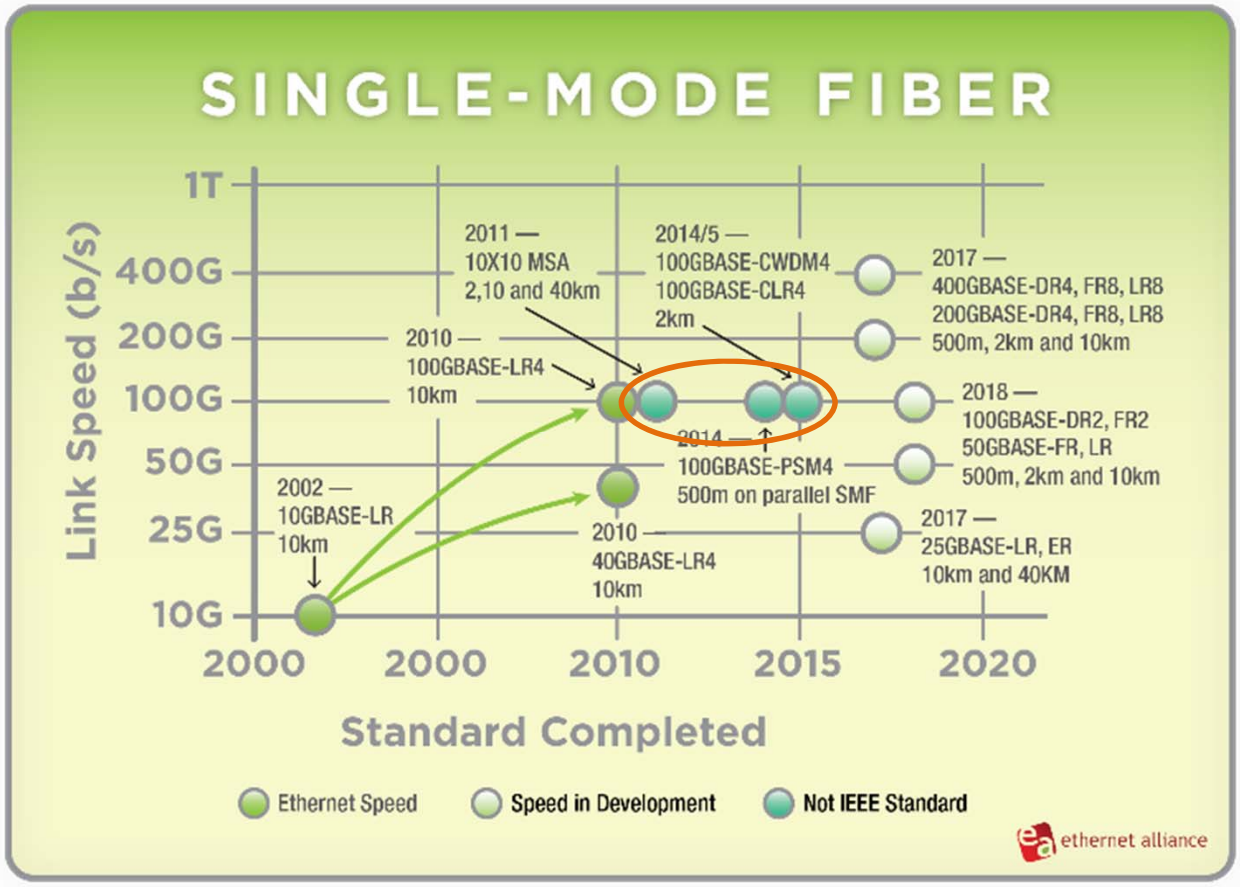
Increase number of fibers
10G SR → 40G SR4

Increase number of wavelengths
Single λ → WDM

MMF Paths to Higher Data rates in IEEE

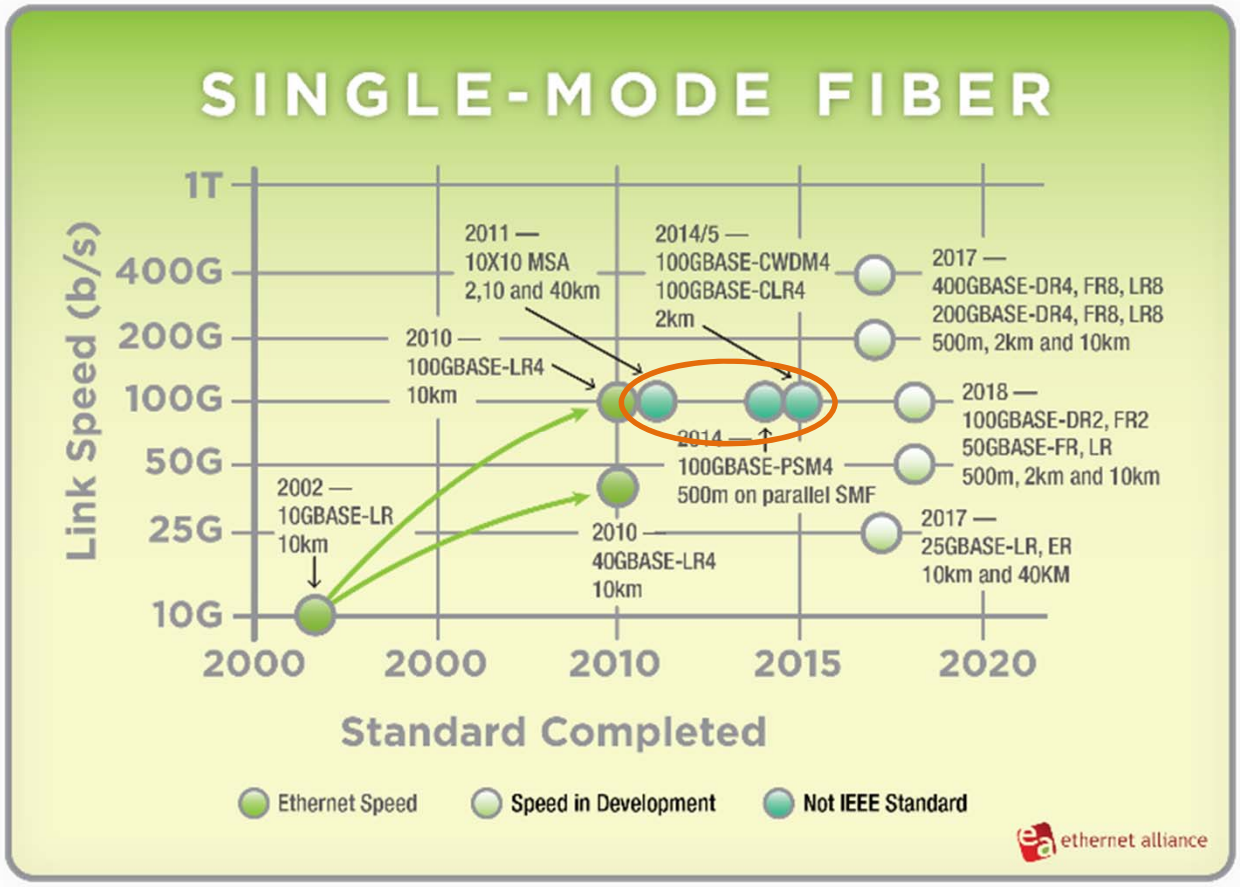
- Higher baud rates – *faster VCSEL's*
- Increased encoding level – *PAM4 in 802.3cd*
- Parallel fiber – *LC → MPO connectivity*
- *WDM not yet adopted in IEEE for MMF*
  - *But being considered!*

Singlemode Fiber Roadmap



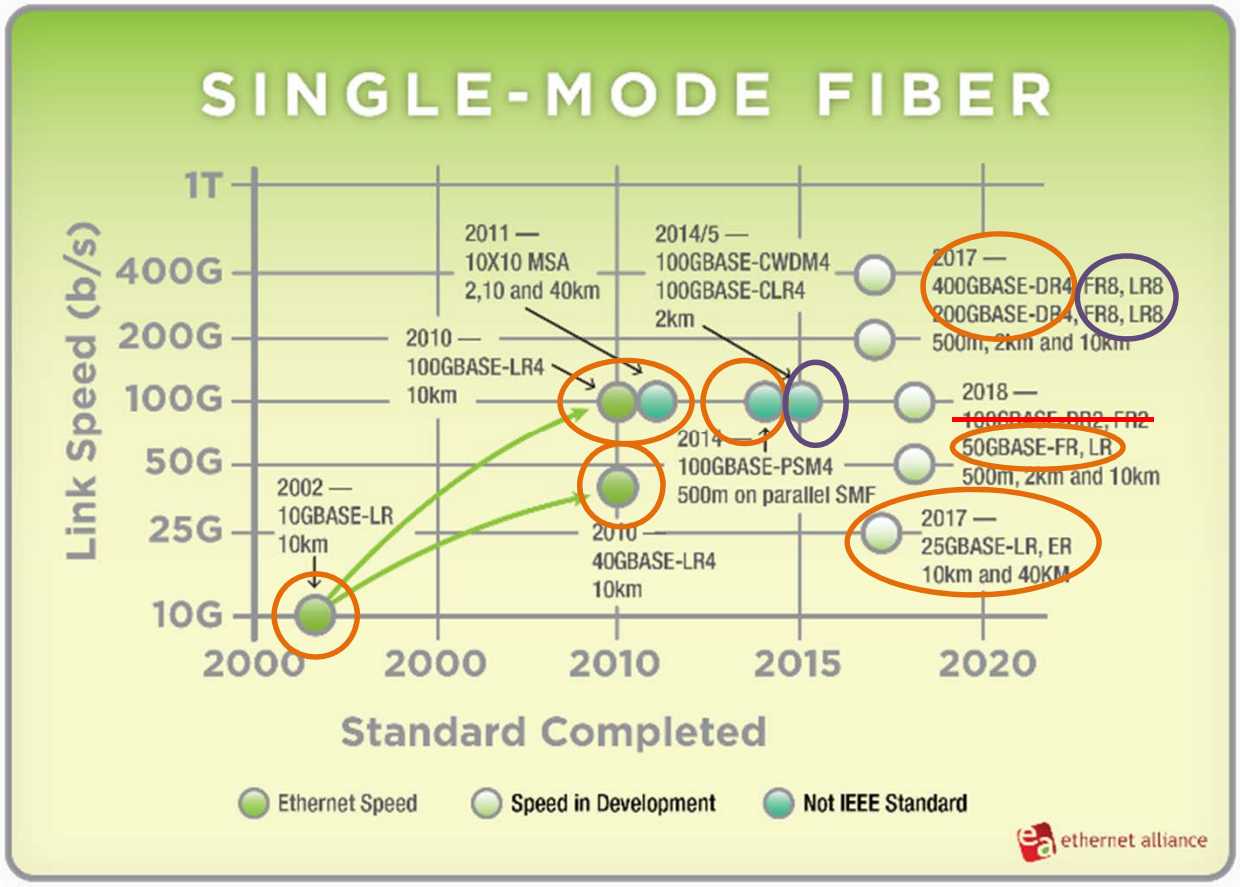
- Similar to MMF
- In addition to standards, PHYs developed in **MSAs**
  - Multi Source Agreement
  - Companies agree to offer solution

Singlemode Fiber Roadmap



- Many MSAs for 100G variants
  - PSM4 - 4x25G, parallel fiber
  - 100G CWDM4
  - 100G CLR4

Singlemode Fiber Roadmap



- Single-λ
  - DR4 – parallel 500m
- WDM
  - FR4 – 2km
  - LR4 – 10km

Fiber Channel Standards

Fiber Channel Speed Roadmap

Product Naming	Throughput (Mbytes/s)	Line Rate (Gbaud)	T11 Specification Technically Complete (Year)*	Market Availability (Year)*
1GFC	200	1.0625	1996	1997
2GFC	400	2.125	2000	2001
4GFC	800	4.25	2003	2005
8GFC	1,600	8.5	2006	2008
16GFC	3,200	14.025	2009	2011
32GFC	6,400	28.05	2013	2016
128GFC	25,600	4x28.05	2014	2016
64GFC	12,800	56.1	2017	2019
256GFC	51,200	4x56.1	2017	2019
128GFC	25,600	TBD	2020	Market Demand
256GFC	51,200	TBD	2023	Market Demand
512GFC	102,400	TBD	2026	Market Demand
1TFC	204,800	TBD	2029	Market Demand

Ethernet similar

← 25G Base-SR

← 100G Base-SR4

← 50G Base-SR

← 200G Base-SR4

Source: FCIA Speedmap v20

FC-PI7 64G / 256G Objectives

- Backward compatibility to 32GFC and 16GFC
- Same external connectors as present connector
  - LC and SFP+ for 64GFC
  - MPO and QSFP56 for 256GFC
- Distances
  - 100m on OM4 cables for 64GFC (2F)
  - 10km on single mode fiber cables for 64GFC (2F)
  - 100m on OM4 cables for 256GFC (8F parallel, 2F WDM)
  - 2km on single mode fiber cables for 256GFC (2F WDM ??)
- PAM4 multi-level encoding (28 GBaud (56GFC))
- Standard Completion 2018

Duplex vs. Parallel in Ethernet

Ethernet options by fiber count

Solution	Reach	40G	100G	200G	400G
Duplex OM3/4	100-150m	BiDi SWDM4	BiDi SWDM4	200G SR1.4 4λ x 50G	NA
Parallel OM3/4	100-150m	SR4/eSR4 4x10G	Gen1: SR10 10x10G Gen2: SR4 4x25G	Gen1: SR4 4x50G	Gen1: SR16 16x25G Gen 2a: SR4.2 4x2λx50G Gen2b: SR8 8x50G Gen3: SR4 4x100G
Duplex SM	2-10km	LR4 (10km) LR4L (2km)	LR4 (10km) CWDM4 (2km)	LR4(10km) FR4 (2km)	LR4(10km) FR4 (2km)
Parallel SM	500m	PLR4	PSM4 DR	DR4 4x50G	DR4 4x100G

Red text = IEEE Standard

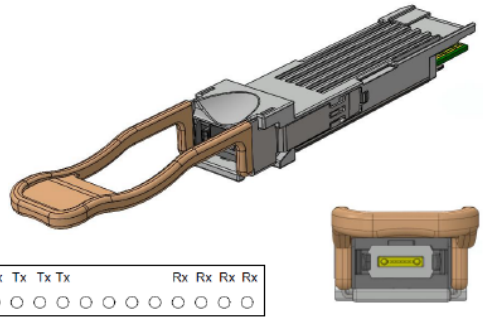
Roadmaps point to 2F and 8F Solutions

- 40G and 100G solutions now have SM/MM with 2 & 8 fiber
- 200G solutions currently in development for 2 & 8 fiber
- Roadmaps for 400G show a path to similar solutions
- Fiber Channel Roadmap shows same trend with 2 & 8 fiber

The real challenge is determining the right solution for the right reach/rate!

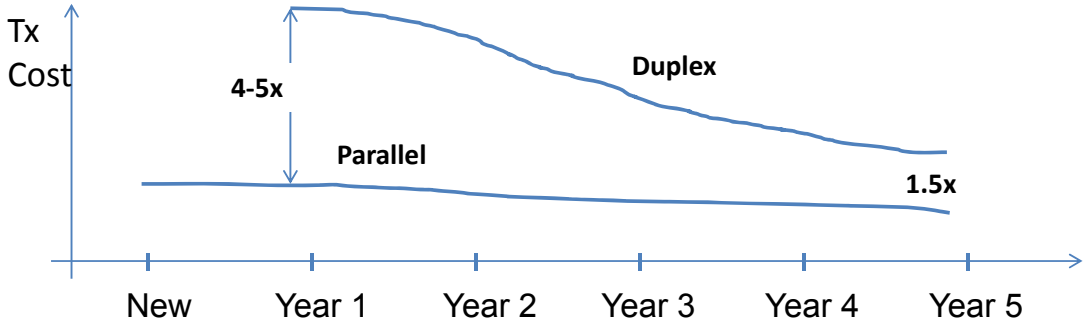
400G Base SR4 Example

400G VCSEL100m SR4 OM4 MMF, (Two VCSEL λ, 4+4 MPO)
DD-QSFP (or OSFP) Form Factor



- 8x50Gbps PAM4 Dual λ VCSEL [looks like SR4 to the end user]
- 4+4 MMF MPO up to 100m OM4
- Uses Same Fiber as 40G SR4 and 100G SR4
- 850nm and 910nm High Reliability VCSEL Sources
- Two VCSEL Wavelengths per Fiber
- Runs at 8x50G but Uses Fiber Like a 4x100G Link
- Commercially available 8x50Gbps Retimer ICs
- Lower cost than any 400G SMF media
- Low power dissipation than any 400G SMF media

Historical Transceiver Cost Cycle



- Parallel uses existing cost reduced components for building next generation transceivers ("flatter" price curve)
- Duplex requires new components (mux/demux, multi lasers, potential signal conditioning, etc.) in order to achieve new data rate (costly components until volume is reached and process optimized)

Summary

- LOTS of work going in IEEE / FC to define higher speeds
- Many companies developing solutions in advance of standards
- Not all solutions being considered will persist

Fiber Technology, Trends and Market Update

Tony Irujo
Sales Engineer
OFS

Sources include:
CRU, IEEE, Cisco, Mathew Burroughs

Bandwidth Drivers

It’s all about The Cloud

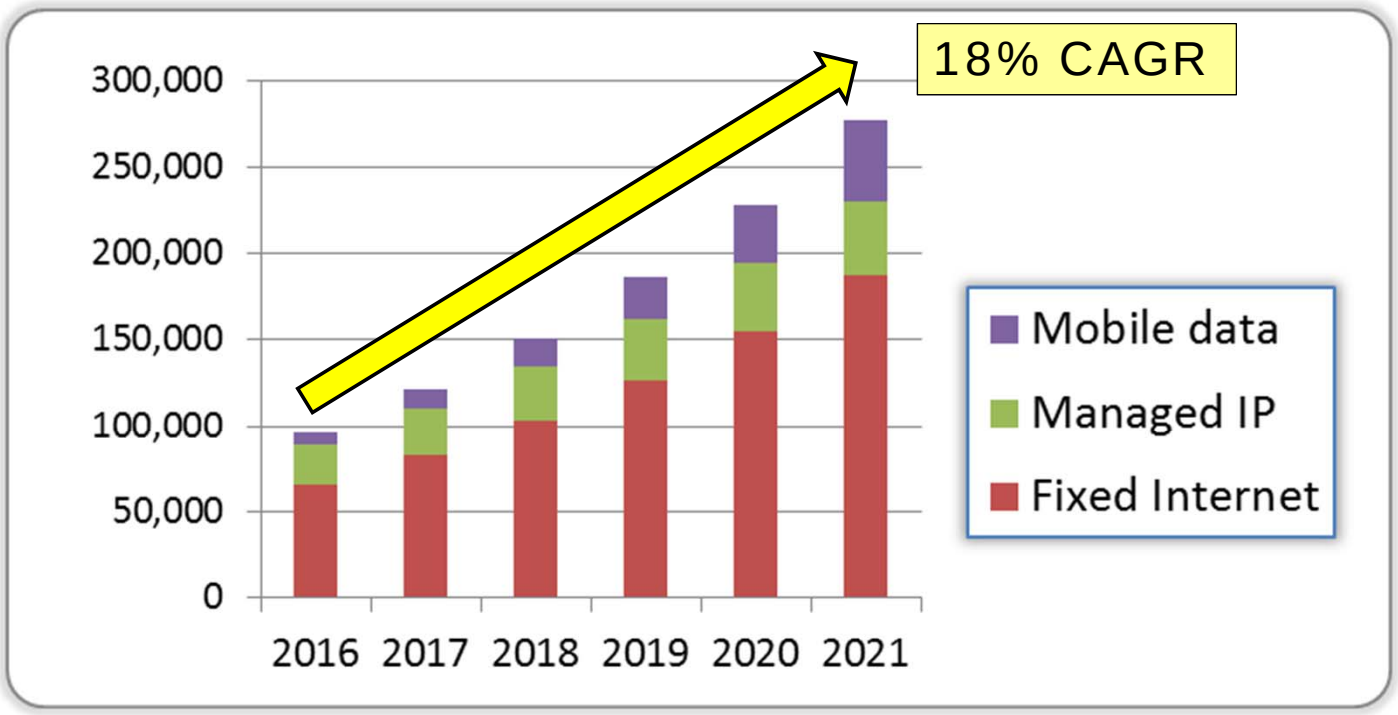
Network Traffic Growth Forecast

	2016	2021
Internet Users *(% of population)*	44%	58%
# Devices & Connections *(per capita)*	2.3	3.5
Avg. Speeds	27.5 Mbps	53.0 Mbps
Avg. Traffic *(per capita per month)*	12.9 Gb	35.5 Gb

Cisco Visual Networking Index (VNI):

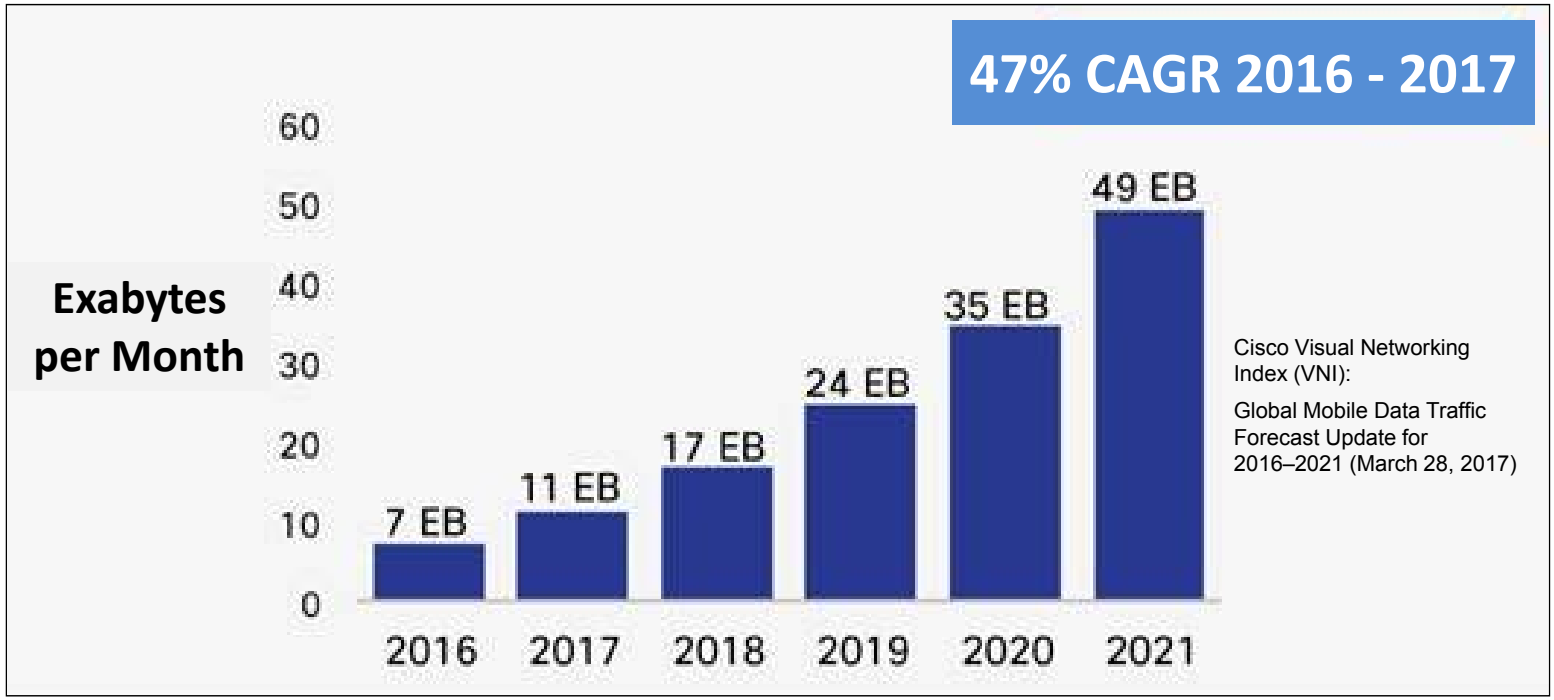
Forecast and Methodology, 2016-2021 (2017)

IP Traffic Growth

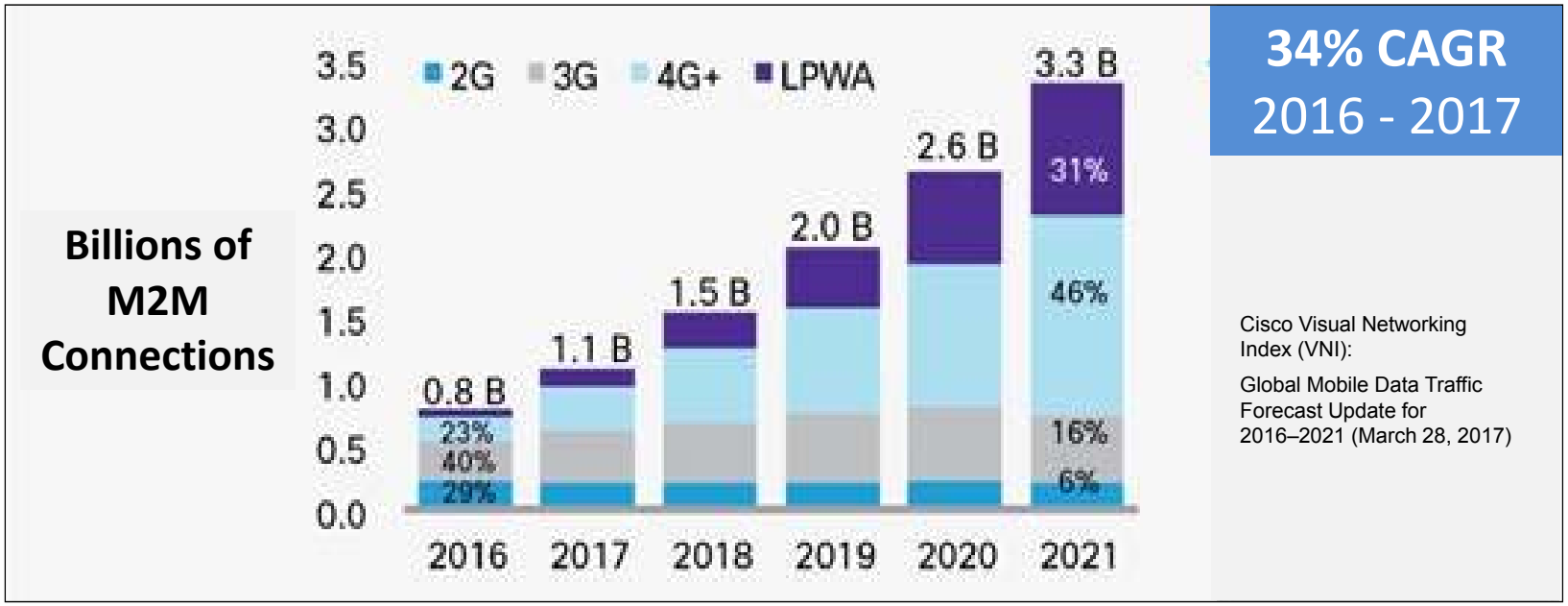


Cisco Visual Networking Index (VNI): Forecast and Methodology, 2016–2021 (June 7, 2017)

Mobile Data Traffic Forecast



Global Machine-to-Machine Growth and Migration from 2G to 3G and 4G+



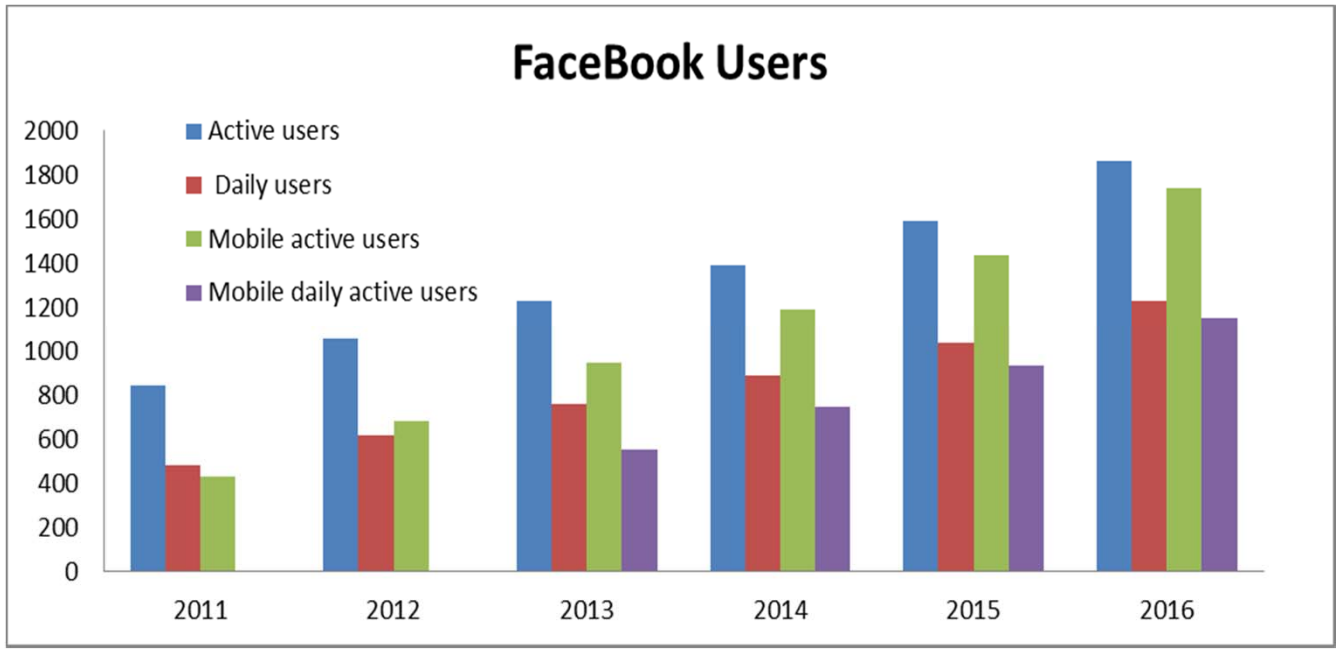
34% CAGR
2016 - 2017

Cisco Visual Networking Index (VNI):

Global Mobile Data Traffic Forecast Update for 2016–2021 (March 28, 2017)

Internet Applications

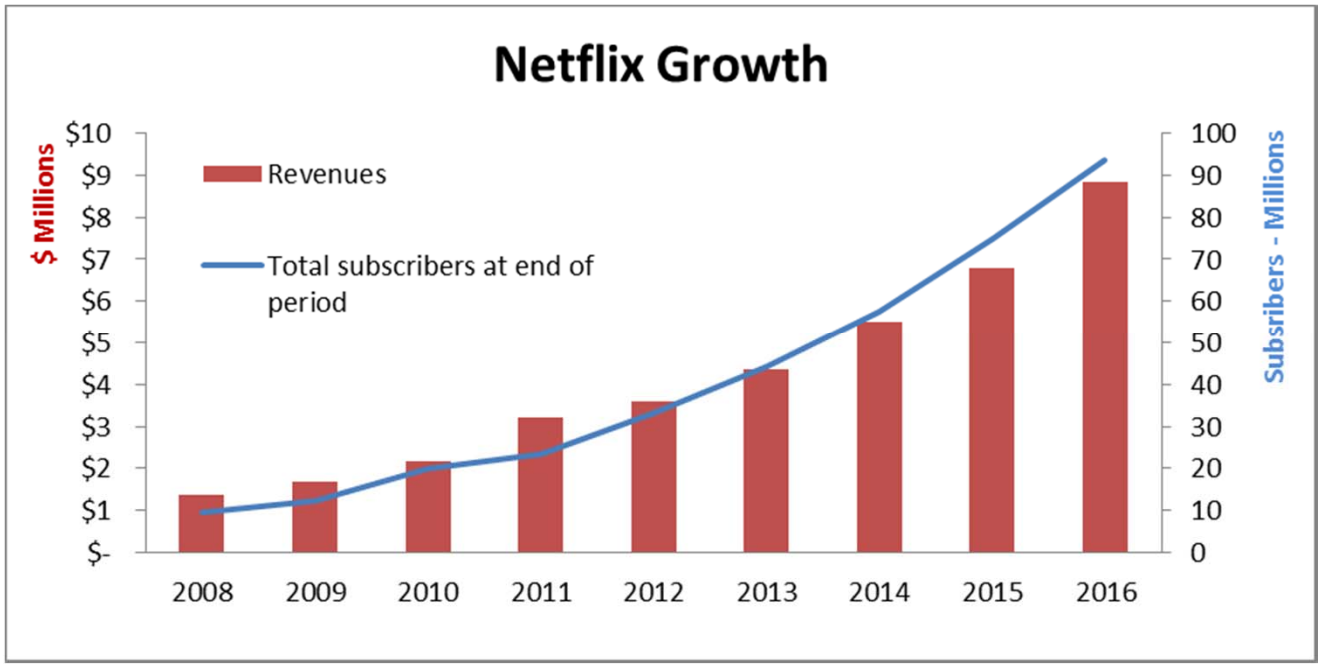
- **Facebook** (as of Dec 2016)
  - 1.86 billion active users, 1.23 billion daily users[1]
  - 1.74 billion active mobile users, 1.15 million daily average mobile users[1]



[1] http://newsroom.fb.com/Key-Facts

Internet Applications

- **Netflix** (as of Dec 2016)
  - 93.8 million members[1]
  - $8.83 billion revenue[1]



[1] http://ir.netflix.com/index.cfm

Fiber Types and Technology

Two Basic Optical Fiber Types

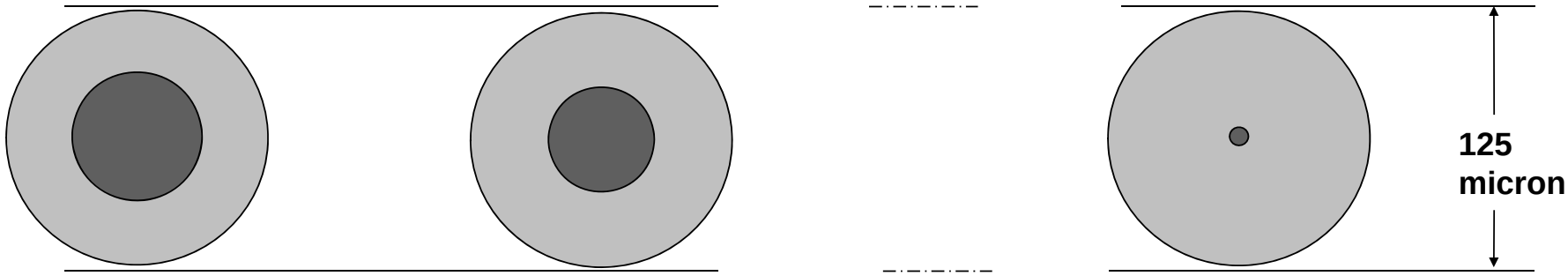
1. Multimode

62.5 micron

50 micron

2. Single-mode

~8 micron

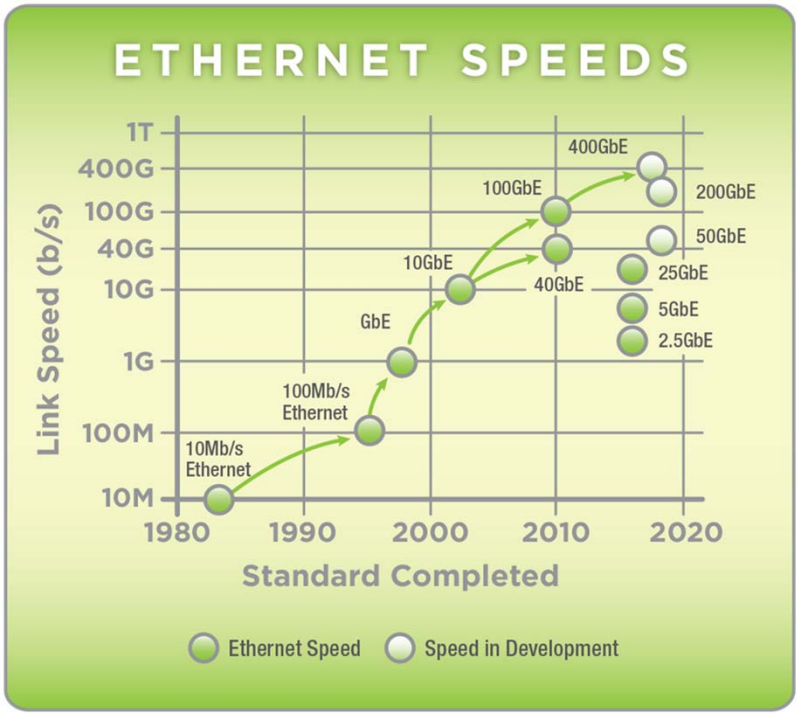


850 nm &
some 1300 nm

Operating
Wavelengths

1310 - 1625 nm

Keeping up with rising Data Rates



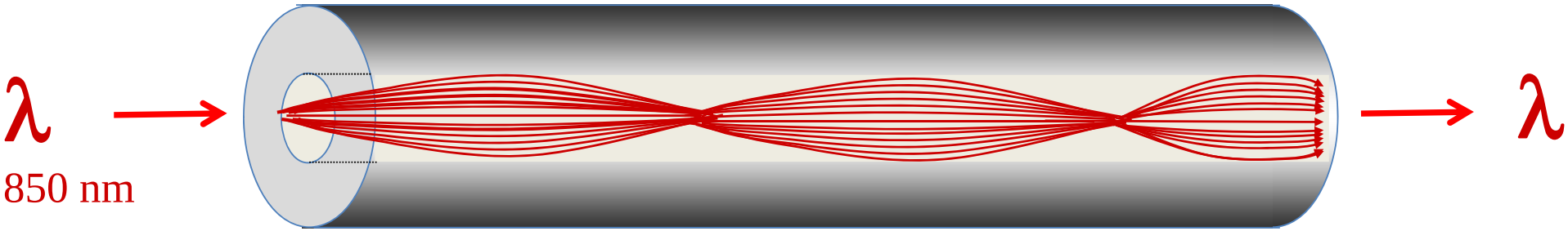
"The 2016 Ethernet Roadmap", Ethernet Alliance, March 2016

ethernet alliance

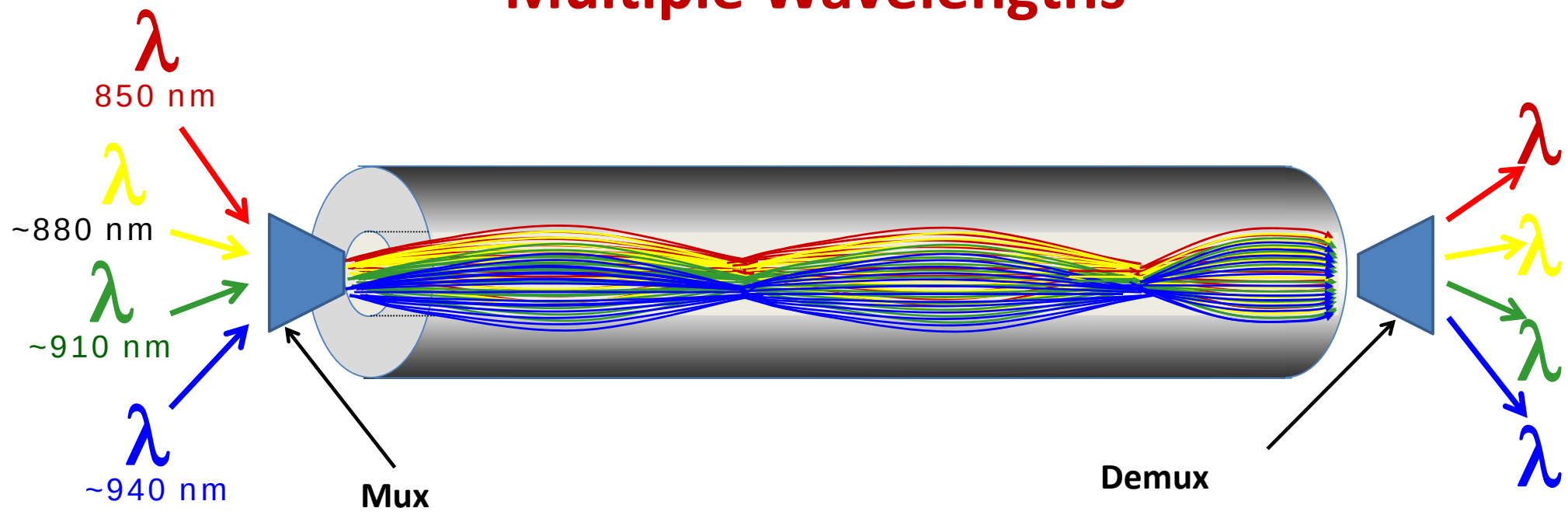
Fiber is up to the task

Multimode Fiber Designation	Multimode Fiber Type	Description	Recommended Application Range
OM1	62.5 um	"FDDI"-Grade	1 Gb/s
OM2	50 um	Dual Window	1 - 10 Gb/s
OM3	50 um	Laser Optimized	10 - 100 Gb/s
OM4	50 um	Laser Optimized *Extended Reach*	10 - 400 Gb/s
OM5	50 um	Wideband for SWDM	400+ Gb/s on fewer fibers

Multimode traditionally operates at one wavelength



OM5 WideBand Multimode – Multiple Wavelengths



OM5 WideBand MMF will take advantage of **Wavelength Division Multiplexing** (WDM) technology.

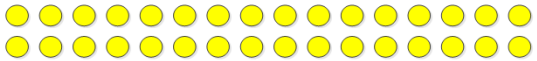
- Same as commonly used on Singlemode fiber:
  - **CWDM** (Course Wavelength Division Multiplexing)
  - **DWDM** (Dense Wavelength Division Multiplexing)

- For Multimode, it will be called **SWDM** –

***Short* Wavelength Division Multiplexing**

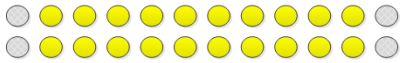
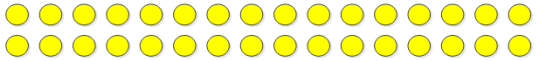
Parallel QSFP MM Fiber Migration Path

SWDM ⇩

	10G/Fiber	25G/Fiber	25G/λ - 4λ/Fiber
10G		N/A	N/A
25G	N/A		N/A
40G		N/A	N/A
100G			
400G	N/A		

Duplex MM Fiber Migration Path

SWDM ⇩

	10G/Fiber	25G/Fiber	25G/λ - 4λ/Fiber
10G		N/A	N/A
25G	N/A		N/A
40G		N/A	N/A
100G			
400G	N/A		

Singlemode Fiber Types

(by **ISO 11801** Cabling Standard convention)

SM *Cabled* Fiber Designation	Wavelength *(nm)*	Max CABLE Loss *(dB/km)*	Cable Type	Typical Reach *(meters)*
OS1	1310 & 1550	1.0	Typically Tight Buffer	2000
OS1a	1310, **1383**, 1550	1.0	Typically Tight Buffer	2000
OS2	1310, 1383, 1550	0.4	Typically Loose Tube	10,000

Singlemode Fiber Types
(by **ITU-T** Fiber Recommendation convention)

SM Fiber Designation / Category	SM Fiber Sub-Type / Class	Description
G.652	G.652.A or G.652.B	Legacy
	G.652.C or **G.652.D**	Low Water Peak
G.657	G.657.A1 G.657.A2 G.657.B2 G.657.B3 / A3	Bend-Insensitive

MM or SM? Speed, Reach, Cost…

- **Up to 10G** *(Enterprise & Campus Backbones, "Simple" Data Centers)*
  - Multimode up to **600m** (~2000 ft.)
    - OM3 to 300m
    - OM4+ to 600m
- **40G & 100G** *(Data Centers, High Performance Computing)*
  - Multimode up to **150m** (~500 ft.)
    - OM3 to 100m
    - OM4 to 150m

Total installed cost of a Multimode system continues to be less expensive than the cost of a Singlemode system.

MM vs. SM Cost Considerations

PMD	Fiber Type	Relative Transceiver Cost	Power Consumption *(Watts, max)*
10GBASE-SR	MM	1	1
10GBASE-LR	SM	2	1 – 1.5
40GBASE-SR4	MM	4	1.2 – 1.5
40GBASE-LR4	SM	20	3.5
100GBASE-SR10	MM	8	3.5 – 4
100GBASE-LR4	SM	100	3.5 – 5

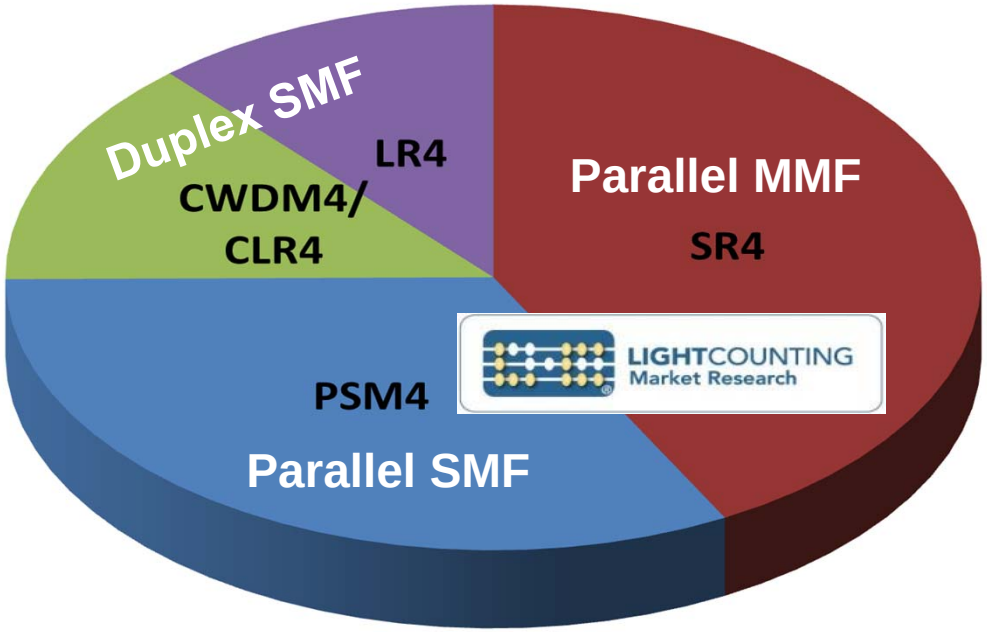
MM continues to be more cost effective than SM for short reach

- ✓ **Cost of optics (transceivers) dominates link.**
- ✓ **Power Consumption of MM optics is typically less than SM.**

Cost References:
www.sanspot.com
www.cdw.com
June 2017

Power Consumption References:
www.finisar.com
www.fit-foxconn.com
Aug. 2017

100GbE QSFP28 Consumption in 2016



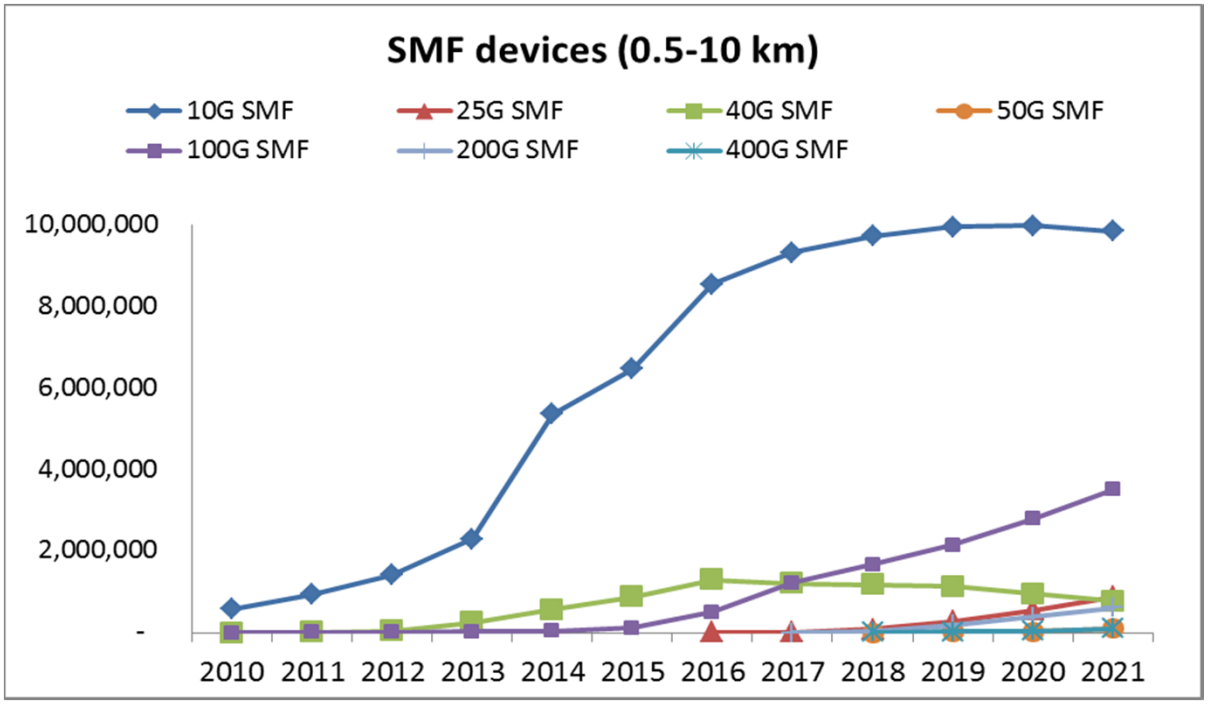
- Chart shows units shipped
- Short-reach SR4 modules had the greatest individual contribution to 2016 shipments of QSFP28 modules

Chart courtesy of Dale Murray, LightCounting

LightCounting Ethernet Transceivers Forecast

Singlemode

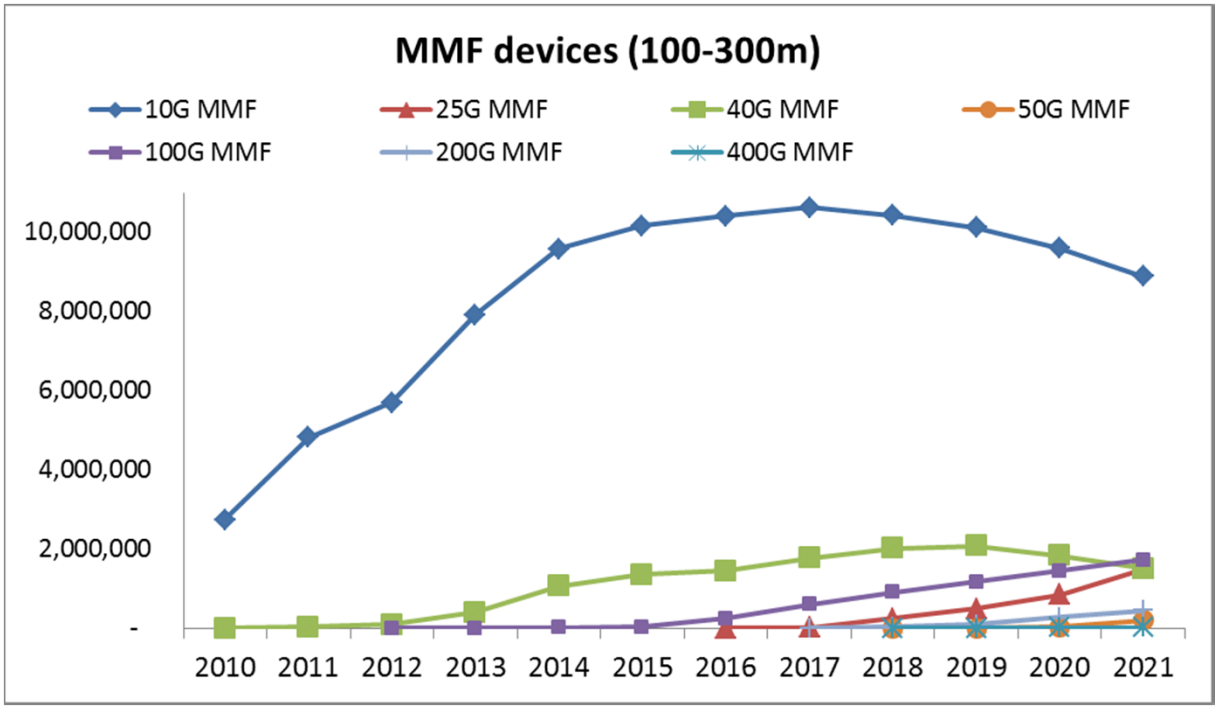
September 2016



LightCounting Ethernet Transceivers Forecast

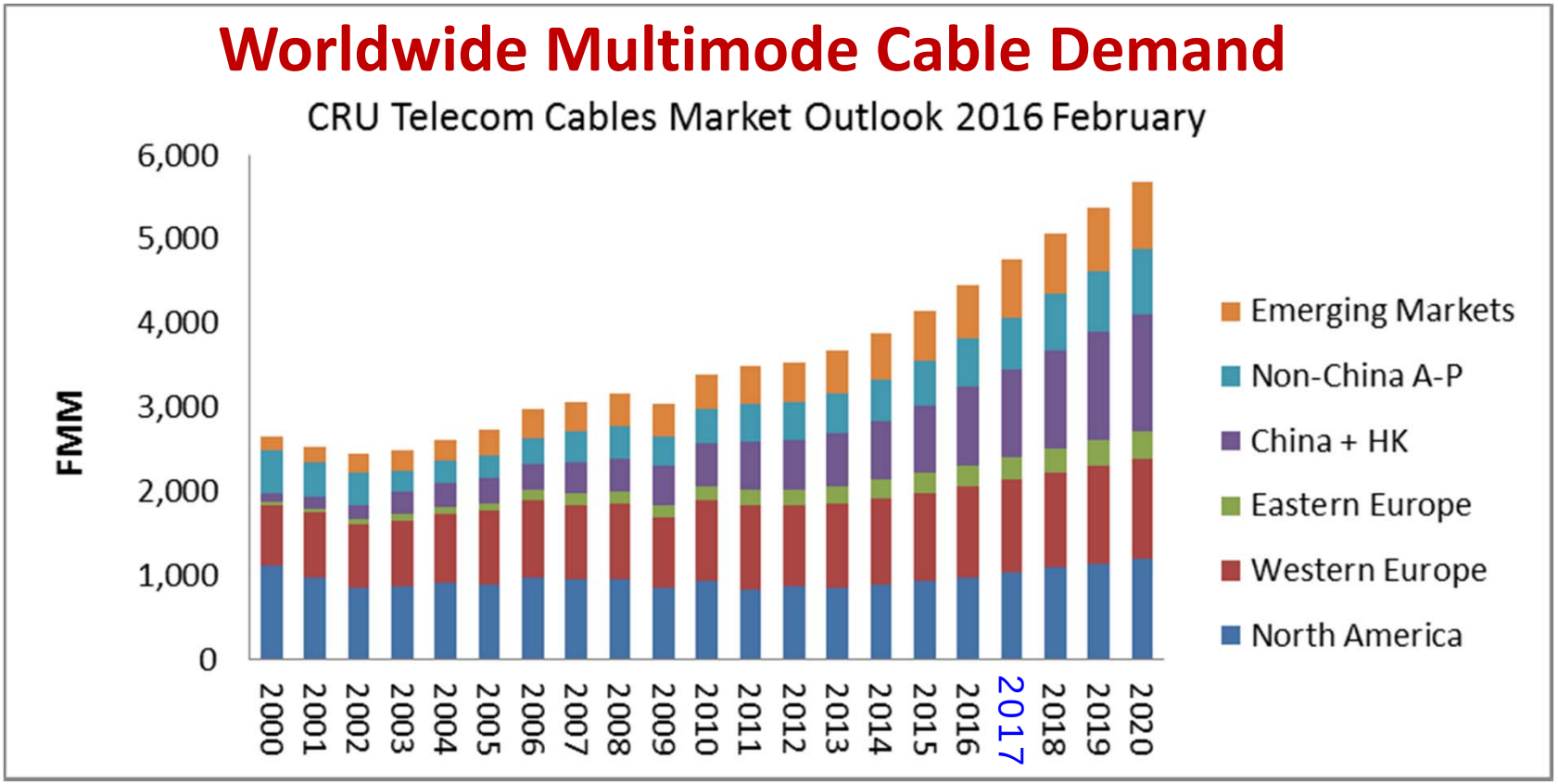
Multimode

September 2016

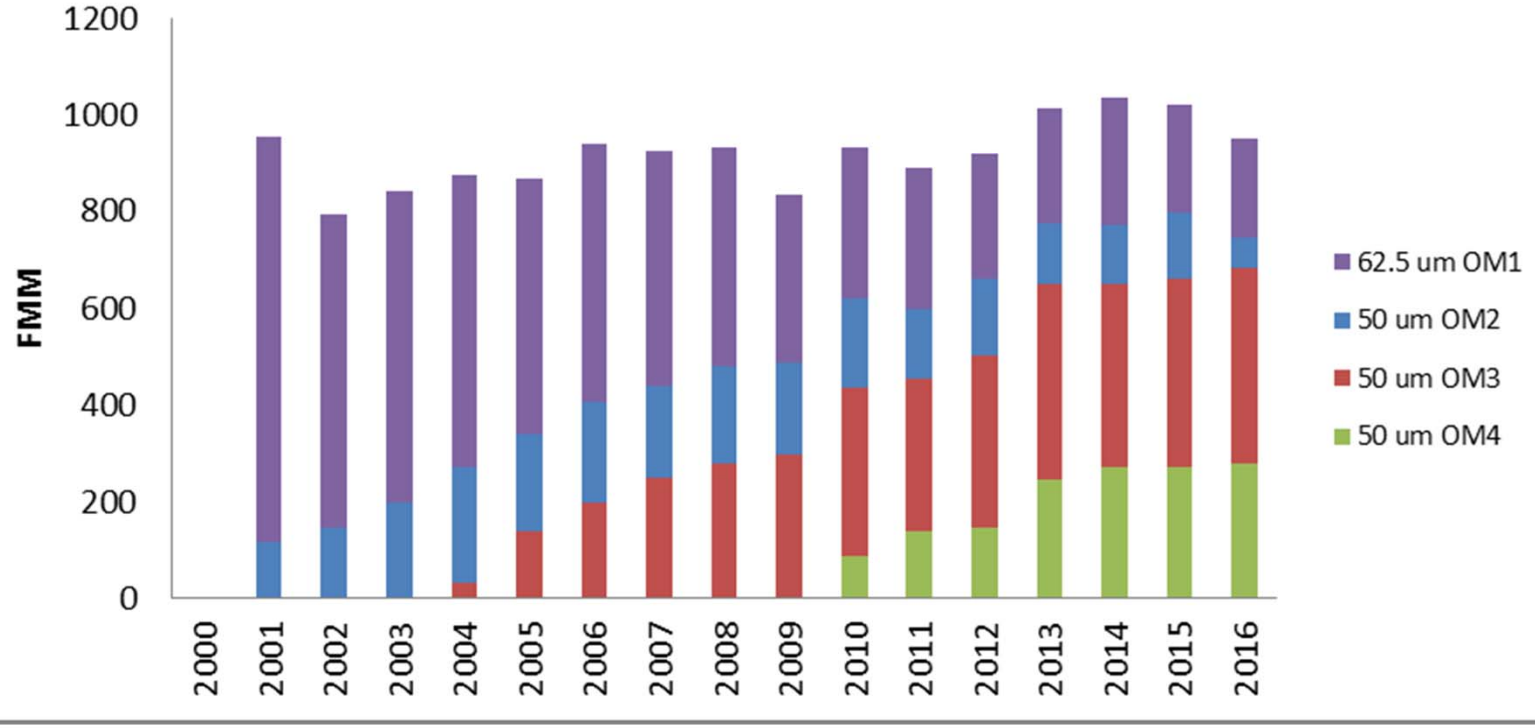


Fiber Market Trends

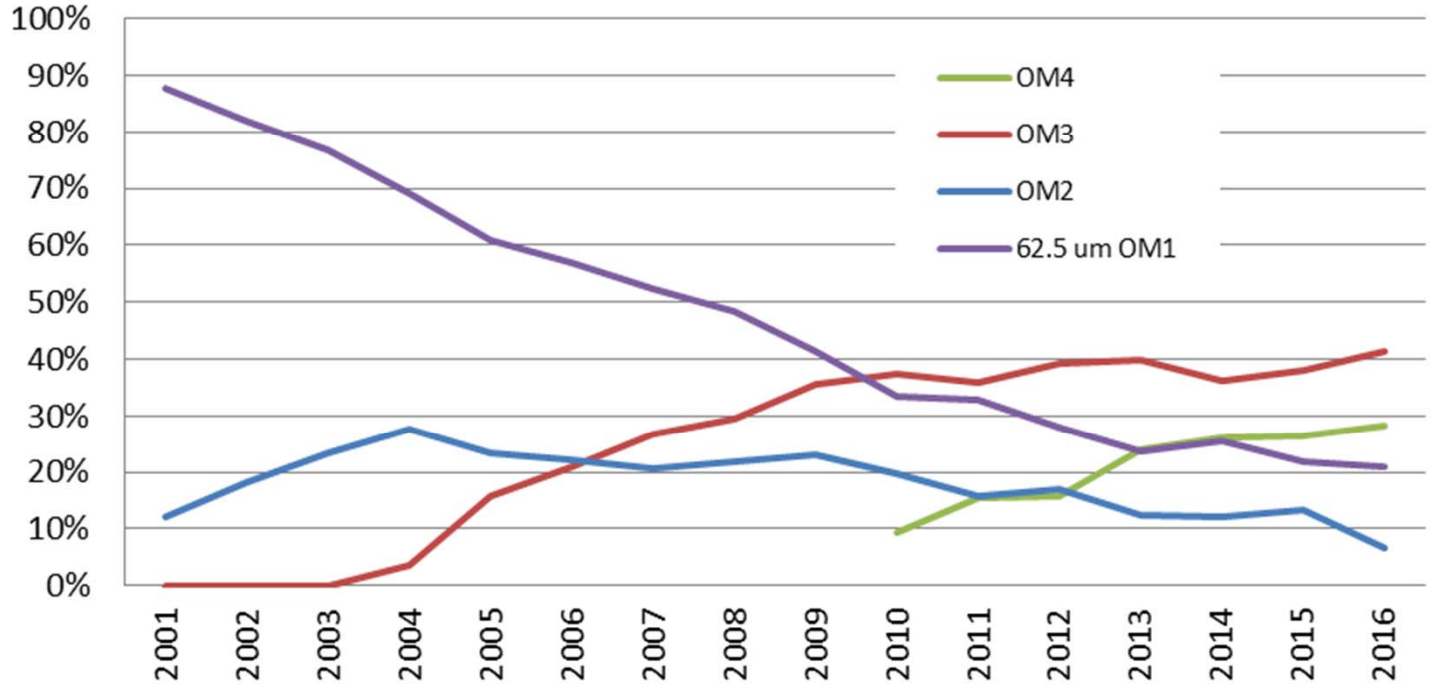
Worldwide Multimode Cable Demand



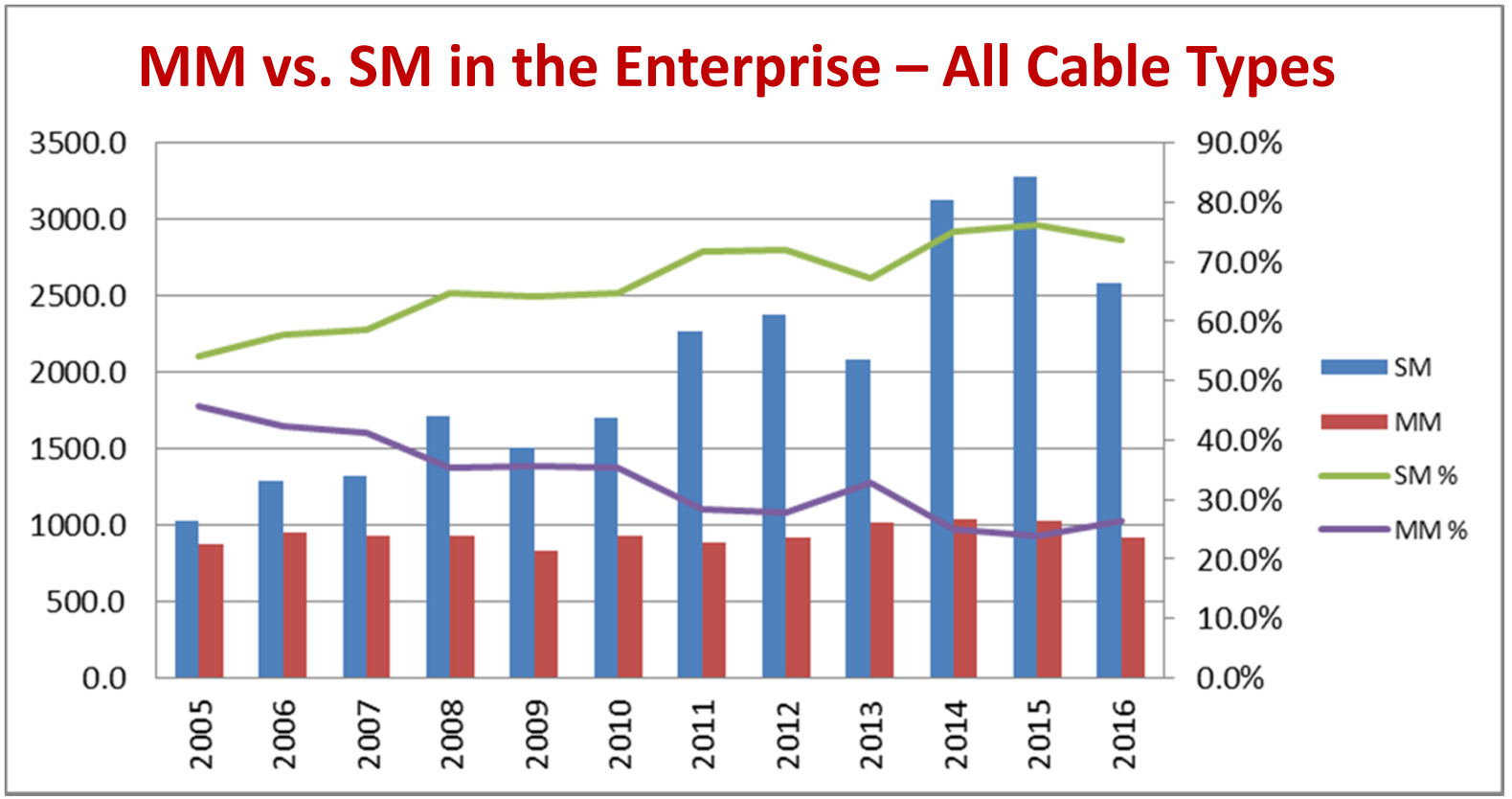
NAR Multimode Fiber Volume by Type (Burroughs)



NAR Multimode Fiber Mix by Type (Burroughs)



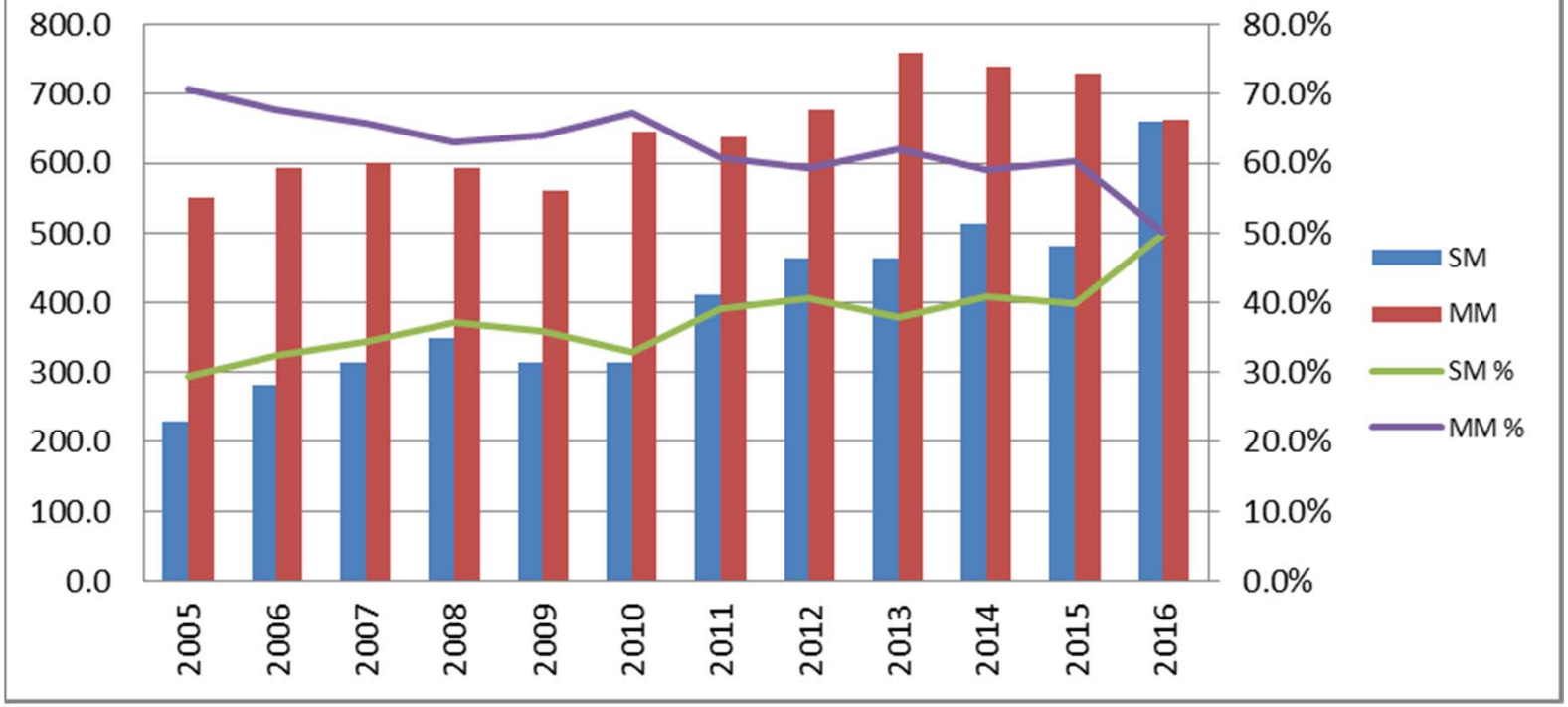
MM vs. SM in the Enterprise – All Cable Types



Source:

Burroughs NAR MMultimode Market Report

MM vs. SM in the Enterprise – Tight Buffer Cable



Source:

Burroughs NAR MMultimode Market Report

Conclusions

- ✓ Bandwidth demand continues to grow, driving the need for increased deployments of optical fiber.
- ✓ Data Rates are increasing at ever faster rates *(10G → 40G → 100G → 200G → 400G)*
- ✓ OM1 and OM2 MM fibers are becoming obsolete.
  OM5 is the next generation of MM for high speed SWDM applications *(Data Centers)*.
- ✓ Industry has moved to Low / Zero Water Peak SM fiber *(G.652.D)*.
  Industry steadily moving to Bend-Insensitive SM fibers *(G.657.xx)*.
- ✓ MM links continue to be more economical than SM for short reach *(transceiver cost)*.

Standard and Non-standard Transceivers Update

Robert Reid, Sr. Technical Manager

Panduit Inc.

Transceiver Macro Trends

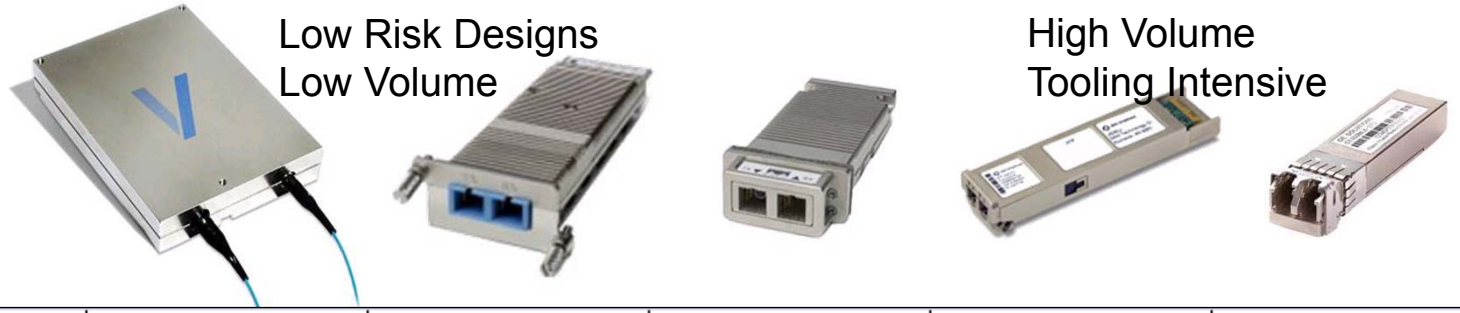
- Support of Installed Base: 16/32GFC, 40GbE, 100GbE, 128GFC support (& beyond) on installed MMF
- Lane rates > 25 Gb/s: Technology enabling VCSEL operation at 50 Gb/s and beyond (future generations of single/multi lane optics)
- Wideband MMF (OM5): Standardization of wideband multimode fiber enabling WDM transmission
- Shortwave WDM (SWDM): Multiplexing multiple lanes onto single fibers reducing fiber count (duplex-LC interface) for 40GbE, 32GFC and above

10G Transceiver History

High Cost → Low Cost

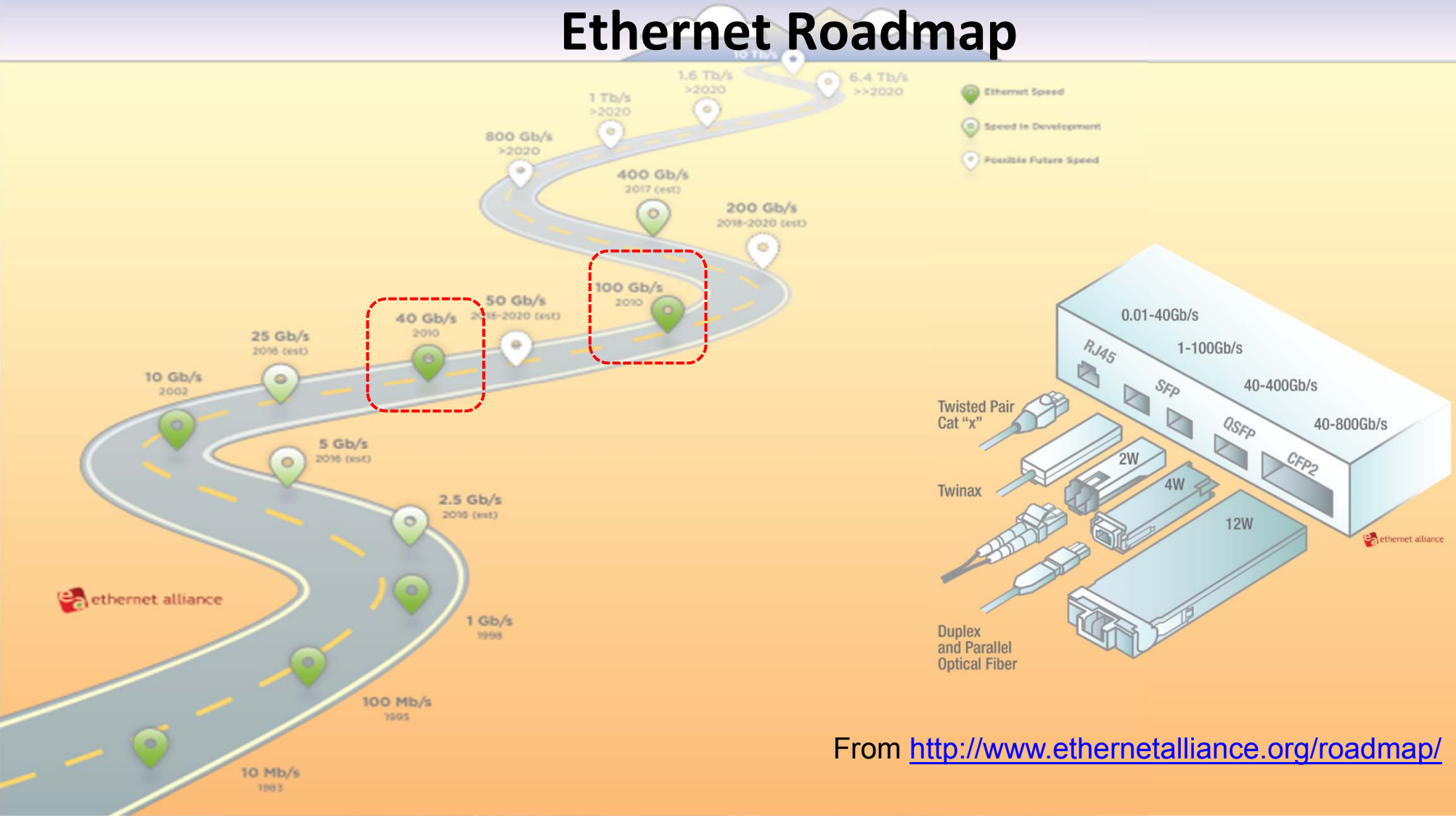
Low Risk Designs
Low Volume

High Volume
Tooling Intensive



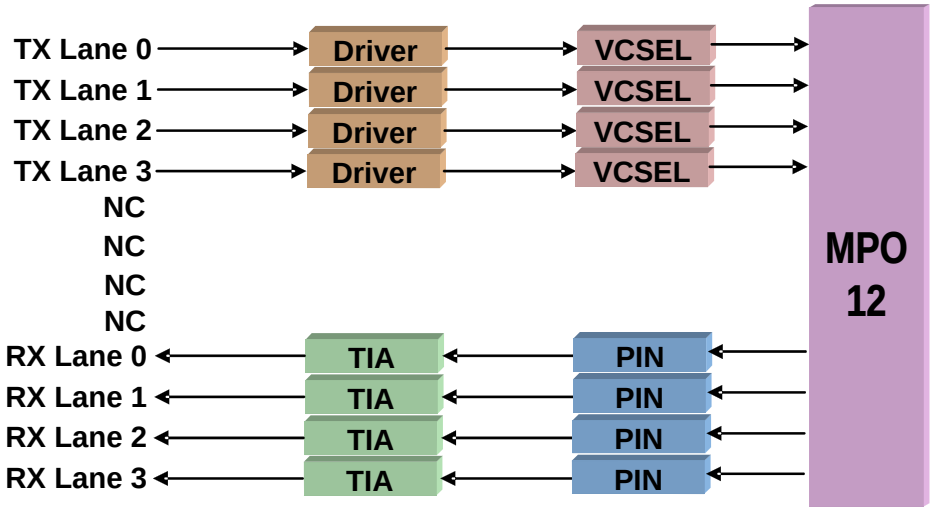
Item	300 Pin	XENPAK	X2	XFP	SFP+
Size (sq. in.)	10	6.75	5	2.2	1.2
Power (Watts)	10	8	4	2.5	1
Density	4	8	16	16/32	48

Ethernet Roadmap

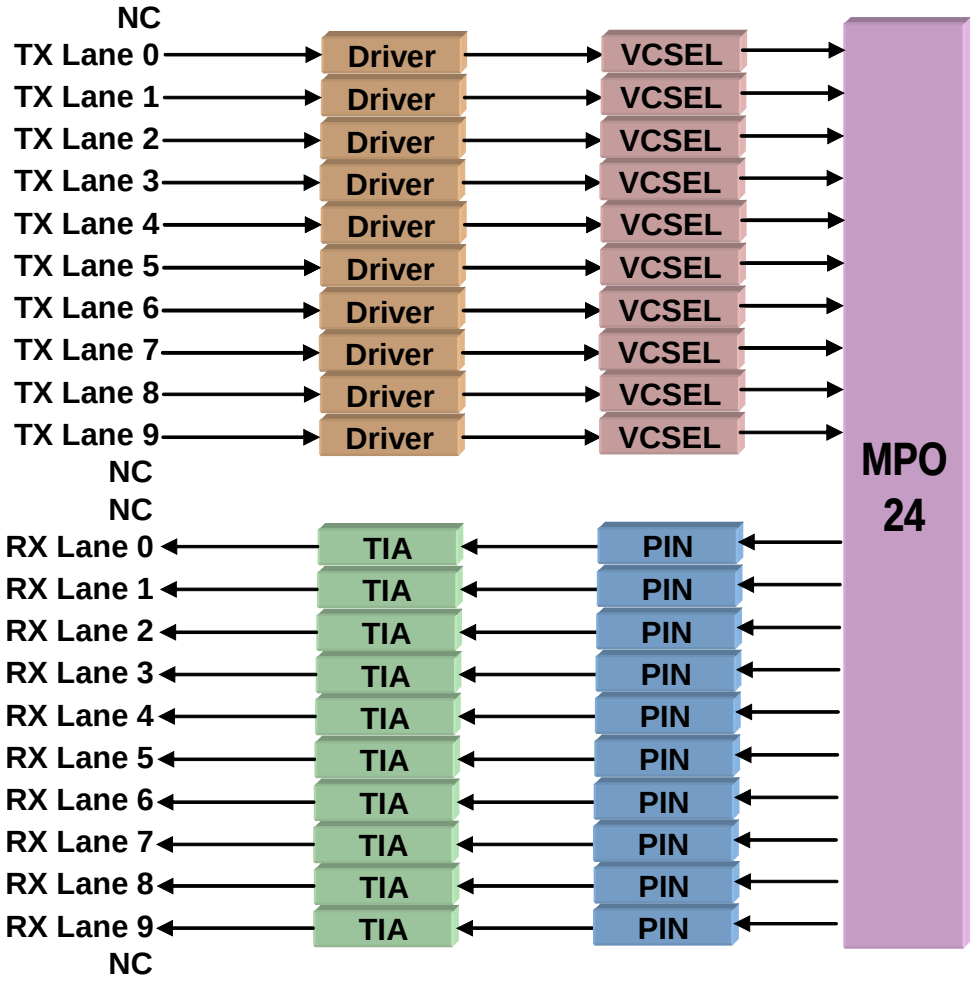


From http://www.ethernetalliance.org/roadmap/

IEEE 40GBASE-SR4



100GBASE-SR10

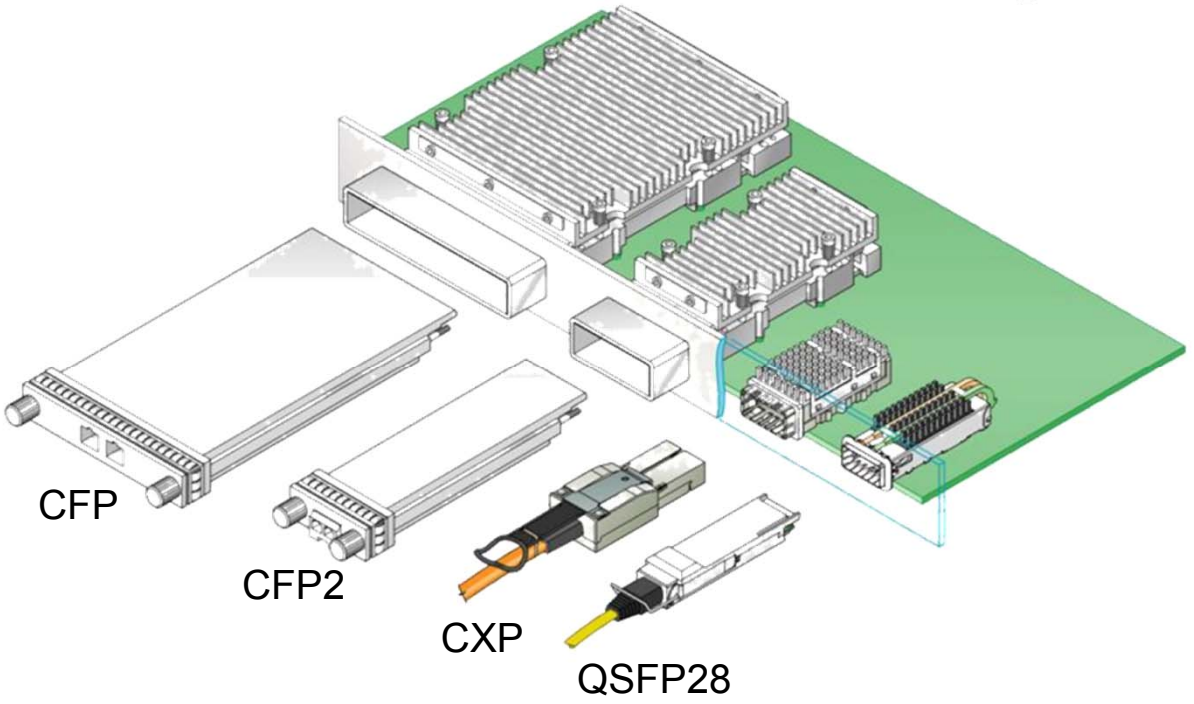


>10G Transceiver Roadmap

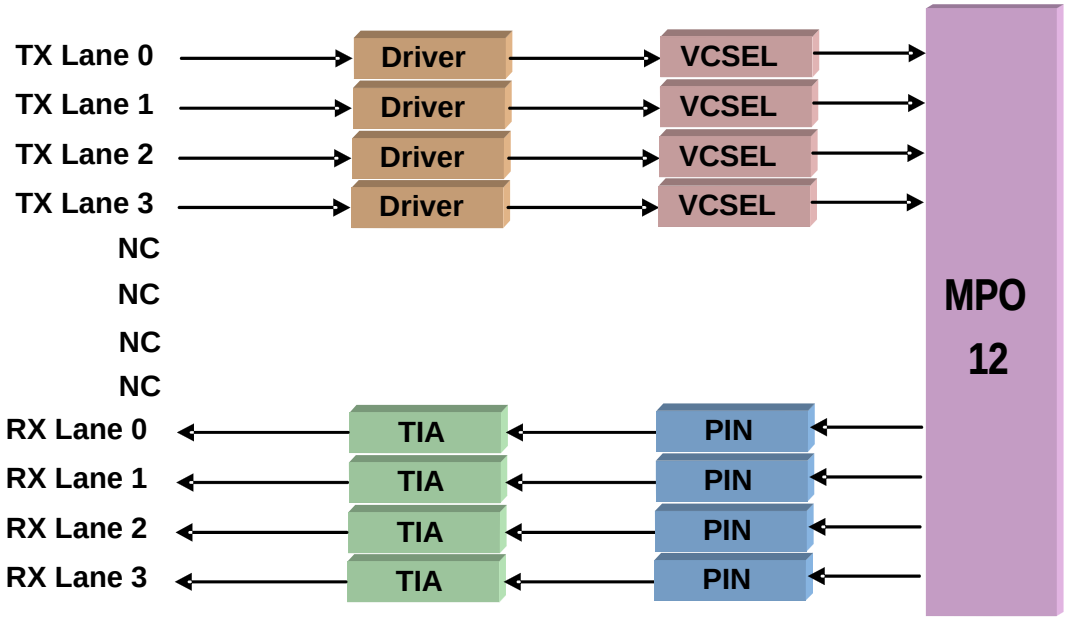
High Cost → Low Cost

Low Risk Designs
Low Volume

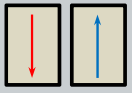
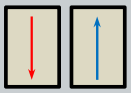
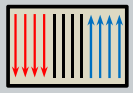
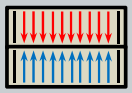
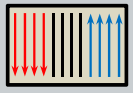
High Volume
Tooling Intensive



100GBASE-SR4



Technology & Standards

Application	10GBASE-SR	25GBASE-SR	40GBASE-SR4	100GBASE-SR10	100GBASE-SR4**
Data Rate	10 Gbps	25 Gbps	40 Gbps	100 Gbps	100 Gbps
IEEE Std	802.3ae	TBD	802.3ba	802.3ba	802.3bm
Form Factor	SFP+	TBD	QSFP+	CFP, CXP	QSFP28, CFP4
Fiber Type	OM3/4	OM3/4	OM3/4	OM3/4	OM3/4
Reach*	300/400m	70/100m?	100/150m	100/150m	70/100m
# of Fibers	2	2	12 (8 used)	24 (20 used)	12 (8 used)
Connectors	 Duplex LC	 Duplex LC	 12f MPO	 24f MPO (2 x 12)	 12f MPO
Schematic					

802.3 Media Device Interface (MDI)

*1.5 dB Link Budget

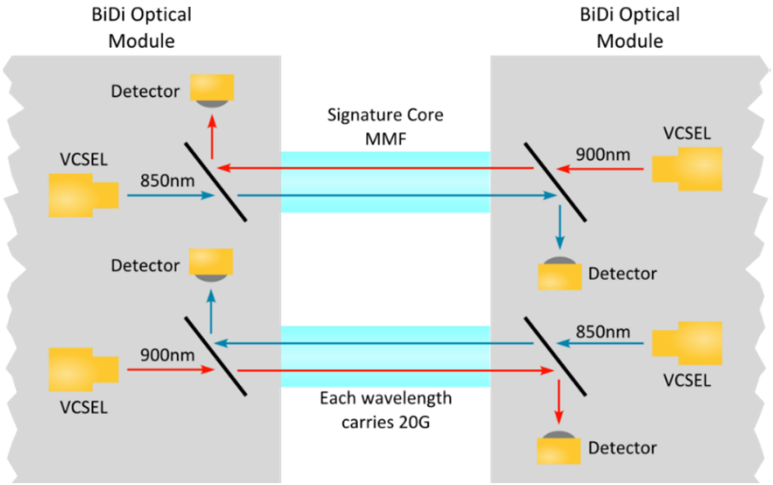
**IEEE P802.3bm approved May 10, 2015

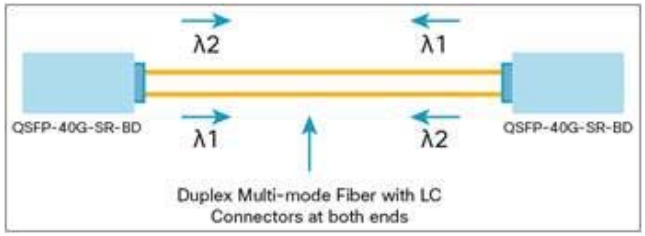
40GBASE-eSR4 'Extended'

- "Extended Reach" transceivers now available from multiple vendors
- Operates as 4 x 10G
  - QSFP+ has 2.5X edge-density as 10GBASE-S
- Operates as 1 x 40G
  - 300m/400m (OM3/OM4) vs. 100m/150m for SR4
- Lower cost alternative to SM (40GBASE-LR4 QSFP+)
  - Lower CAPEX - Estimated 75%
  - Lower OPEX - 50% power dissipation (1.5W vs. 3.5W)

Bidirectional SFPs

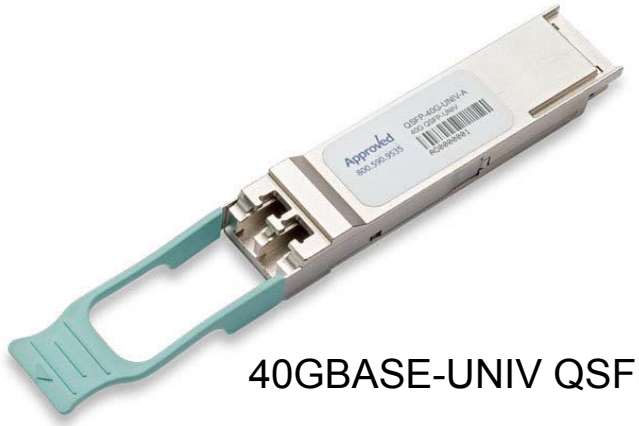
- BiDi – short for bidirectional
- 40G Ethernet over two fibers (100G coming!)
- Allows use of existing LC infrastructure
- Uses Wavelength Division Multiplexing – 2 x 20 Gbps signals





‘Universal’ Transceivers

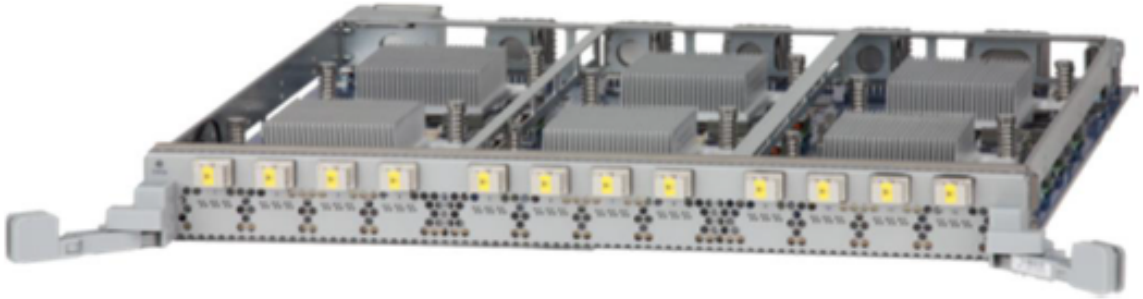
- Addresses customer concerns around the reduced distances with 40GBASE-SR4
- Migrations from existing 10 to 40GbE networking without requiring redesign/expansion of fiber network
- Supports operation over 150 m of OM3 or OM4
- Can be used for up to 500 m and with both 40GBASE-LR4 and 40GBASE-LRL4

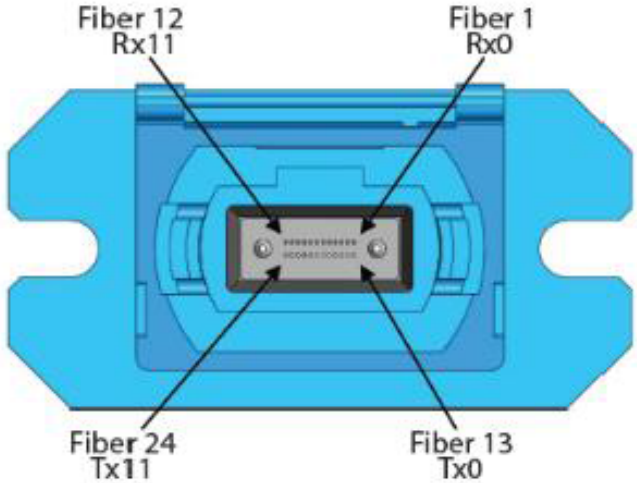


40GBASE-UNIV QSFP

Embedded Multispeed Ports

12 Port MXP Triple-speed line card for Arista 7500E Series switch
Channel mapping for 24f MXP triple-speed port





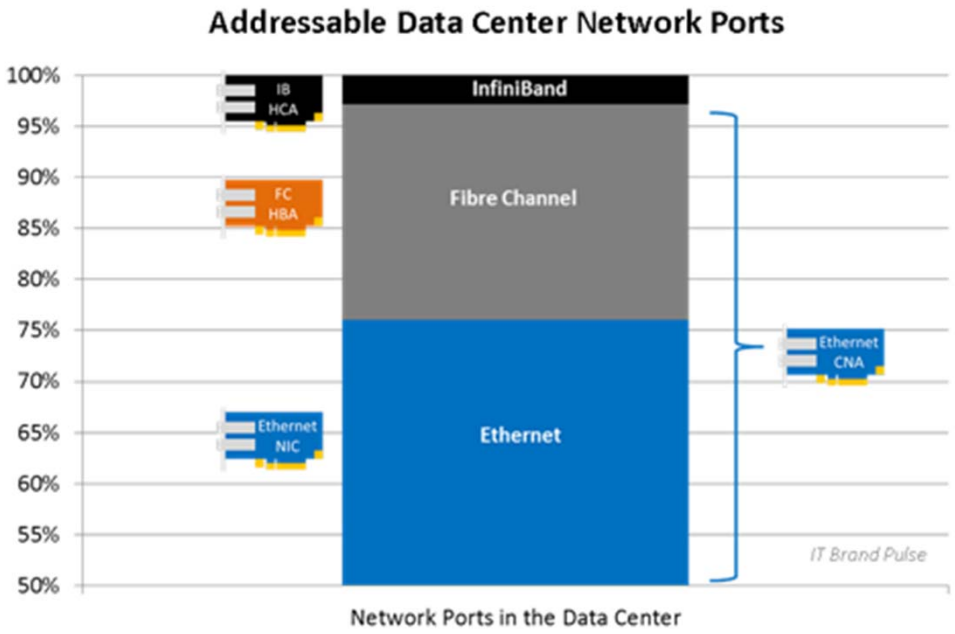
Fiber Channel Roadmap

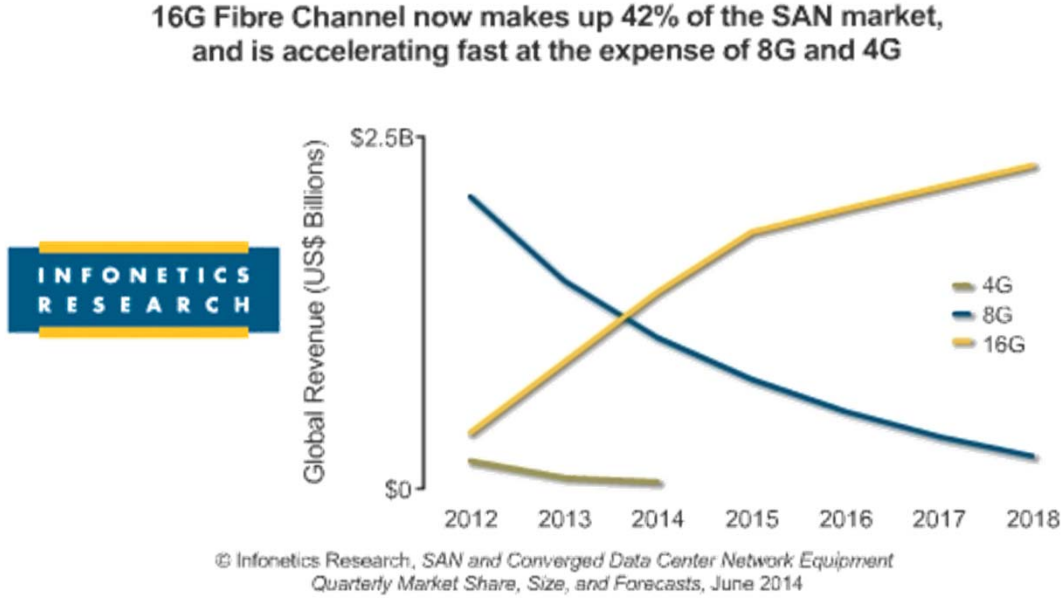
Product Naming	Throughput (Mbytes/s)	Line Rate (Gbaud)	T11 Specification Technically Complete (Year)*	Market Availability (Year)*
1GFC	200	1.0625	1996	1997
2GFC	400	2.125	2000	2001
4GFC	800	4.25	2003	2005
8GFC	1,600	8.5	2006	2008
16GFC	3,200	14.025	2009	2011
32GFC	6,400	28.05	2013	2016
128GFC	25,600	4X28.05	2014	2016
64GFC	12,800	56.1	2017	2019
256GFC	51,200	4X56.1	2017	2019
128GFC	25,600	TBD	2020	Market Demand
256GFC	51,200	TBD	2023	Market Demand
512GFC	102,400	TBD	2026	Market Demand
1TFC	204,800	TBD	2029	Market Demand

GEN 6 Fibre Channel

GEN 7 Fibre Channel

Fiber Channel Market





- Mainstream/High Volume use of 16G HBAs & Targets with 16GFC
- Marriage of 16GFC capability with SSDs
- Launch of Cisco MDS 97K Multilayer Directors
- Less FC Edge switches being sold - More Directors

FC 64Gb/s Transceiver

New Brocade FC Optics Module Technology

64G QSFP

2km SM version for ICL & 16G MM reach version for switch port applications (details below)

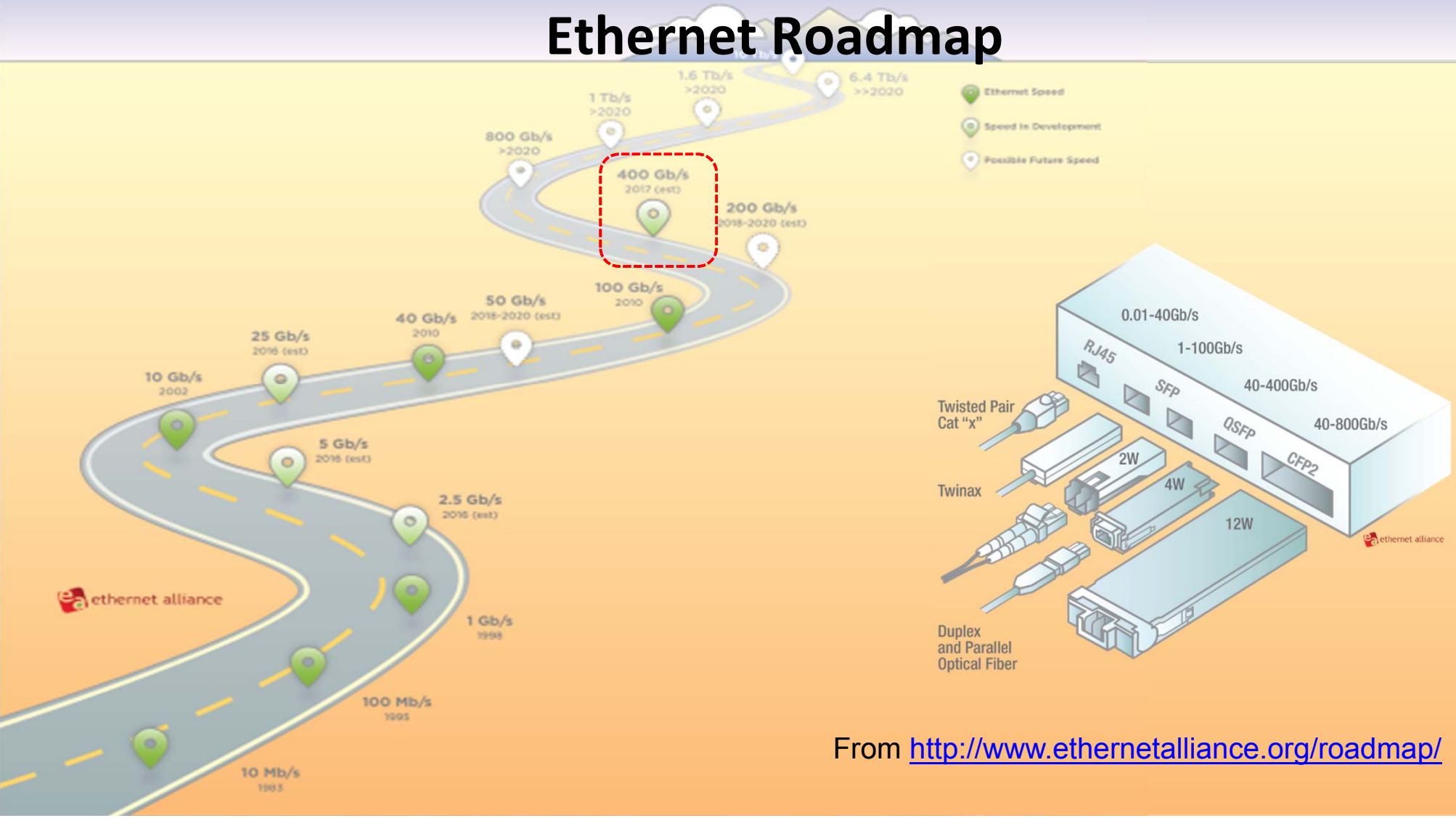
The following table provides an overview of the differences between standard SFP+ optics and QSFPs. The QSFP leverages the same technology as standard SFPs but combines four channels into one optic to better support high density SAN solutions.

Specification	SFP+	QSFP
Speed Grade	2/4/8/16Gb	4/8/16Gb
Operating Distance	Same	Same

FC Higher Speed Efforts

- FC 32G PI-6 (bit rate 28.05Gbps)
  - Published & SFP+ Transceivers shipping
- FC 128G PI-6P (Aggregate bit rate 4x28.05 Gbps)
  - MMF: 4 parallel lanes of 32G with breakout use cases implied
  - SMF two options: 4 parallel fibers & CDWM
- FC 64G per fiber PI-7 & PI-7P (bit rate 56.1 Gbps per fiber)
  - Discussion to combine both 64GFC/256GFC ongoing (breakout?)
  - Evaluating modulation format (PAM-4 is strong candidate) and 2/4 wavelength solutions
  - WideBand MMF is being introduced as a possible solution and cable plant models based on TIA/IEC standards being considered & modeled

Ethernet Roadmap



From http://www.ethernetalliance.org/roadmap/

Candidate Technology (IEEE)

- Serial - Signaling rate of VCSEL transmitter (40GHz to 60GHz has been demonstrated)
- Parallel - Multiple lane aggregation (SR4, SR10, SR16)
- WDM - Wide Band MMF designed to take advantage of this (new fiber designed to enable 4+ wavelengths)
- Encoding - Conventional is NRZ (two symbols – symbol rate same as bit rate). PAM-4 encodes two bits in one transmission interval

IEEE 802.3bs 400G Proposals

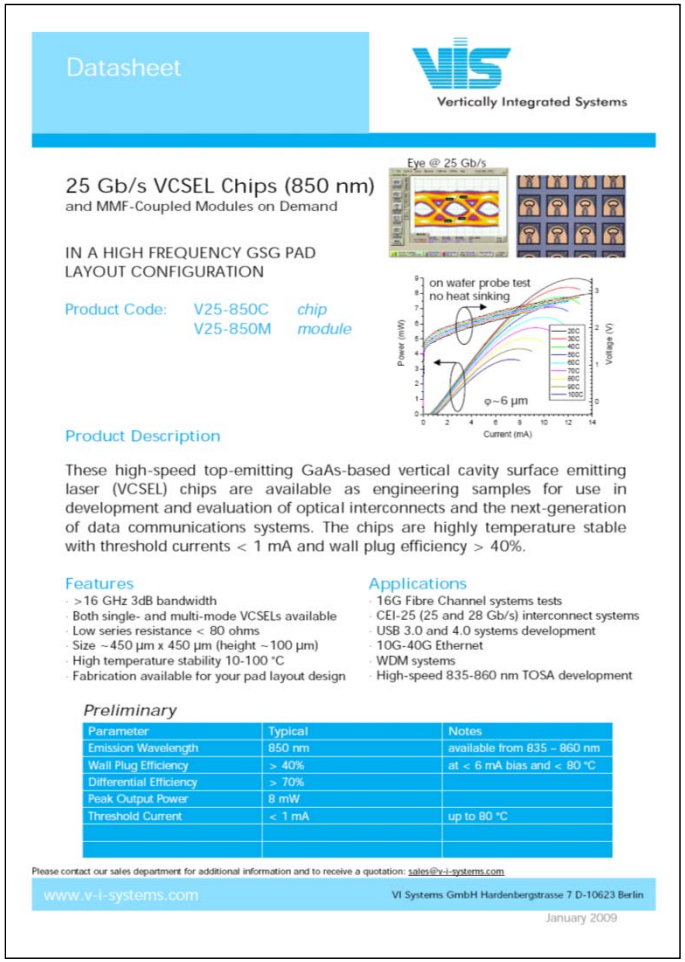
100m MMF	1λ 25G NRZ x16 Fibers				
500m SMF		2λ 50G NRZ PSM-4		1λ 100G PAM-4 PSM-4	
2km SMF		8λ x 50G NRZ x1 Fiber	8λ x 50G PAM-4 x1 Fiber	4λ x 100G PAM-4 x1 Fiber	
10km SMF		8λ x 50G NRZ x1 Fiber	8λ 50G PAM-4 x1 Fiber		4λ x 100G DMT x1 Fiber

100G SR4 Modulation Enabler

Extension of VCSEL emitter done in support of 16Gb/s Fiber Channel short wave transceivers (Finisar work in early 2008)

Several companies have research focused on direct modulation of VCSEL devices to support the serial short wave channel (Avago, Merge Optics, VIS, NEC, etc.)

Impact on 100G MM implementation (4x25G instead of 10x10G)



Datasheet

VIS Vertically Integrated Systems

25 Gb/s VCSEL Chips (850 nm)
and MMF-Coupled Modules on Demand

IN A HIGH FREQUENCY GSG PAD LAYOUT CONFIGURATION

Eye @ 25 Gb/s

on wafer probe test
no heat sinking

Product Code: V25-850C *chip*
V25-850M *module*

Power (mW) Voltage (V) Current (mA) φ~6 µm

Product Description

These high-speed top-emitting GaAs-based vertical cavity surface emitting laser (VCSEL) chips are available as engineering samples for use in development and evaluation of optical interconnects and the next-generation of data communications systems. The chips are highly temperature stable with threshold currents < 1 mA and wall plug efficiency > 40%.

Features
- >16 GHz 3dB bandwidth
- Both single- and multi-mode VCSELs available
- Low series resistance < 80 ohms
- Size ~450 µm x 450 µm (height ~100 µm)
- High temperature stability 10-100 °C
- Fabrication available for your pad layout design

Applications
- 16G Fibre Channel systems tests
- CEI-25 (25 and 28 Gb/s) interconnect systems
- USB 3.0 and 4.0 systems development
- 10G-40G Ethernet
- WDM systems
- High-speed 835-860 nm TOSA development

Preliminary

Parameter	Typical	Notes
Emission Wavelength	850 nm	available from 835 – 860 nm
Wall Plug Efficiency	> 40%	at < 6 mA bias and < 80 °C
Differential Efficiency	> 70%	
Peak Output Power	8 mW	
Threshold Current	< 1 mA	up to 80 °C

Please contact our sales department for additional information and to receive a quotation: sales@v-i-systems.com

www.v-i-systems.com VI Systems GmbH Hardenbergstrasse 7 D-10623 Berlin

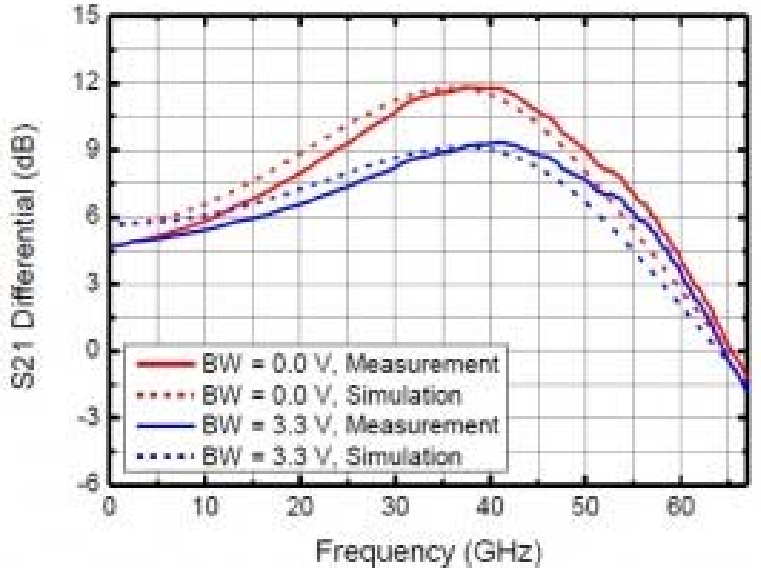
January 2009

Modulation Enabler (update)

VI Systems demonstrates the performance of their latest generation of 850nm vertical surface emitting laser (VCSEL) to transmit at a data rate of 54 Gbit/s over 2.2 km of multimode fiber.

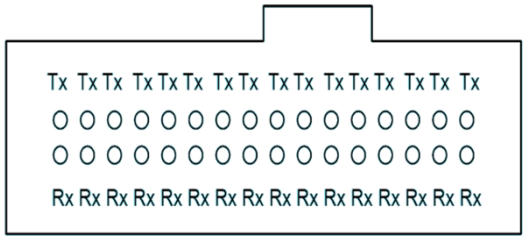
BERLIN, Germany, Apr 11, 2016

Customer samples of the VCSEL drive available now June 27, 2017



Move toward 16 fiber units?

- Moving from 10G per lane to 25G per lane
- Likely upgrade paths (mm) results in units of 4 fiber's:
  - 40G ÷ 10G per fibre = 8 (2x4F) fibers
  - 100G ÷ 25G per fibre = 8 (2x8F) fibers
  - ~~400G ÷ 25G per fibre = **32 (2x16F) fiber's**~~
- Discussions in IEEE/TIA to support:
  - 16-pin MPO connector (TR 42.13)
    - Polarity descriptions that cover n-number of fibre units (TR 42.11)
    - 4 new fibre colors to support 16-fiber ribbons bundles (TR 42.12)

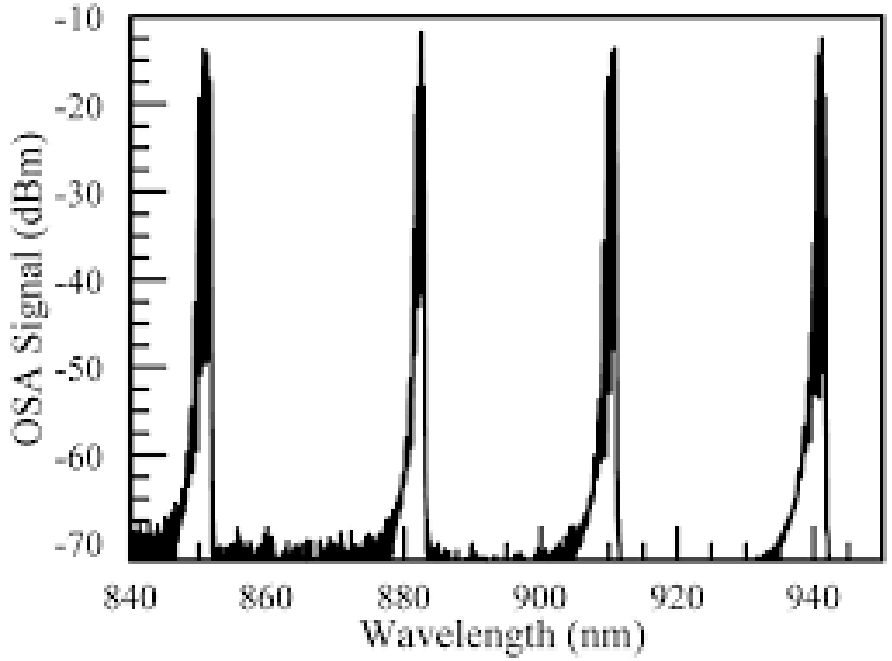


32F/16F MPO?

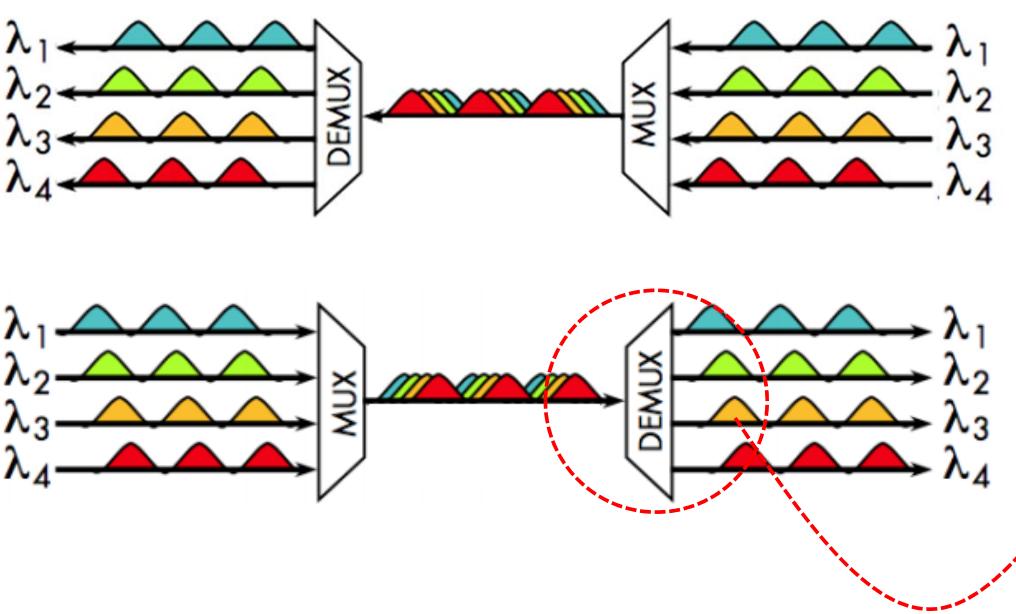
…however

SWDM Module Technology

- SWDM uses multiple VCSELs at different wavelengths around 850 nm to multiplex data streams onto a single fiber
- Passive optical multiplexing of light occurs within the module
- On receive side, wavelengths are demultiplexed (using the same type of passive optic)



SWDM Module Technology



SWDM Module Technology

SWDM Alliance (transceiver, fiber and system vendors) created a “Multi-Source Agreement” (MSA) for transceivers defining use of the 840nm to 953nm wavelengths for the transmission of multiple VCSELs via WDM over WBMMF & non-WBMMF.

Both 40G and 100G QSFP SWDM4 released.

LUMENTUM

FINISAR

SWDM Market Adoption

Pros:

- Extends lifetime of MMF solutions
- Provides legacy (OM3/OM4) cable solution for 40G+
- >100G ‘Toolbox’ item (encoding, line rate & parallel)

Cons:

- Immature SWDM ecosystem - transceivers/fiber expensive
- OM5 modal bandwidth vs. OM4 at 850nm - equal
- Transceiver complexity, high power consumption
- SWDM less flexible; doesn’t support breakout

PAM-4 Multilevel Encoding

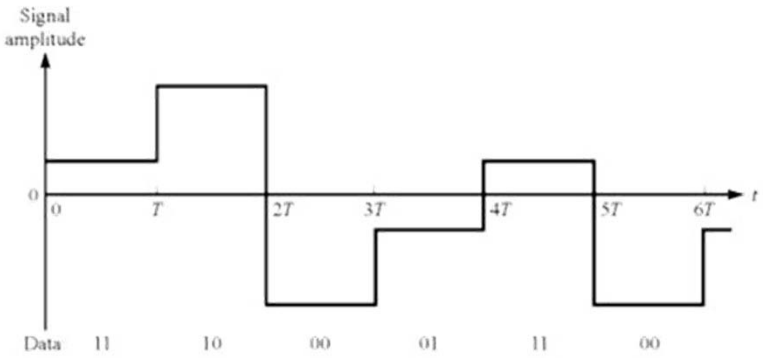
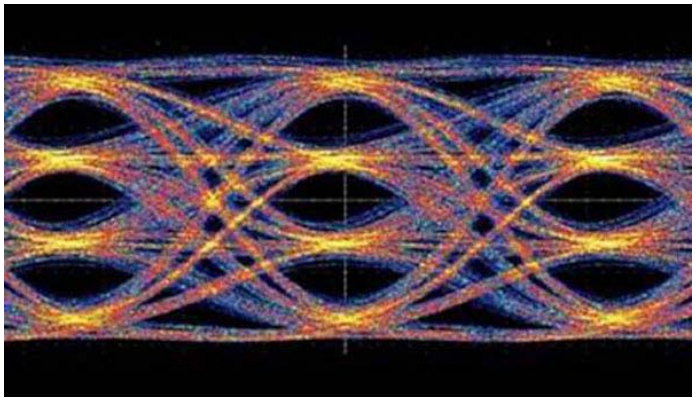


Fig.1 A PAM-4 signal in time domain. T= symbol period.



- 4 distinct pulse amplitudes used
- Amplitude represented by two bits 00, 01, 11, and 10 (a ‘symbol’)
- One of the four amplitudes is transmitted in a symbol period, there are two bits transmitted in parallel (data rate doubled)
- PAM-4 modulation is twice as bandwidth-efficient as binary modulation

400G Fiber Options & Reach

Data Rate	PMD	OM3 50 µm	OM4 50 µm	SM
400G *(in process)*	400GBASE-SR16 (16f x 25G)	At least 100m		N/A
400G *future?*	4f x **4λ** x 25G	At least 100m		N/A
400G	400GBASE-DR4 (4f x 100G) 400GBASE-FR8 (8λ x 50G) 400GBASE-LR8 (8λ x 50G)	N/A		500 m 2 km 10 km

Today's SM transceivers are typically >2x cap-ex of MM, also higher power.

100G SMF Standards Activity

IEEE802.3bm task force named three contending technologies for SMF (link distance ≤2km) at its final closure in 2014.

- CWDM (coarse wavelength-division-multiplexing),
- PSM4 (parallel single-mode fibers with 4 lanes in each direction)
- PAM-8/16 (pulse amplitude modulation with 8/16 levels)

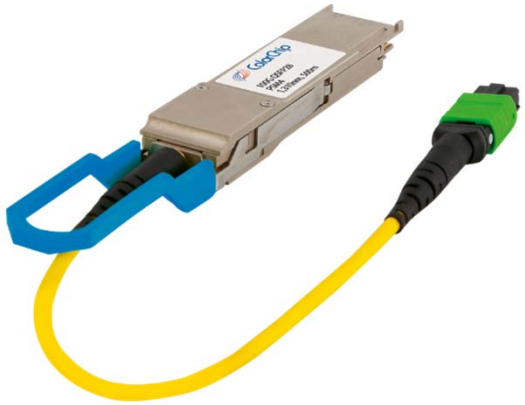
Several multi-source-agreement (MSA) consortia formed.

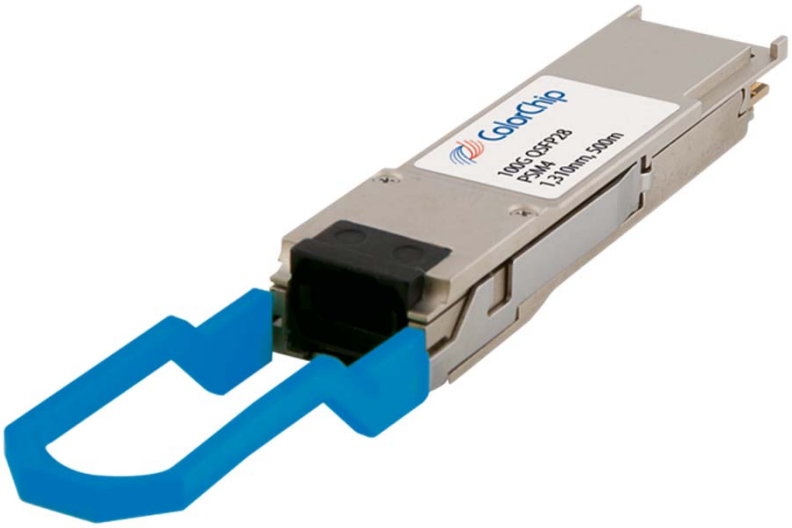
- PSM4 is called “100G PSM4” (psm4.org/)
- CWDM/CWDM4 (cwdm4-msa.org/) & CLR4 (clr4-alliance.org/)
- Companies working on 100G PAM-4, no MSA has been formed

100G PSM4 MSA

- Industry Consortium - Brocade, Delta Electronics, Juniper, Panduit, USConec, Avago, Luxtera, etc.
- Low cost solution to extend reach within the DC for 100G interconnect
- Reach of 500m on parallel (ribbon) SM fiber
  - Sufficient reach for many DCs
  - Max power per lane: 2dBm
- Use of FEC to keep costs down (de-spec'd optics)

100G PSM4 MSA





- 4 integrated modulators & one CW uncooled 1.3μm DFB laser
- MPO connector with support for 8 active fibers
- Reach less than 500 meters (<3.0dB of connector IL in cable plant)
- Breakout possible (same cabling components as 128G FC)

100G PSM4 MSA

WWW.PSM4.ORG

100G PSM4 Specification

Parallel Single Mode 4 lane

9/15/2014

Version 2.0

5.3 100G PSM4 illustrative link power budget

Illustrative power budgets and penalties for 100G PSM4 optical channels are shown in Table 6.

Table 6: 100G PSM4 illustrative link power budget

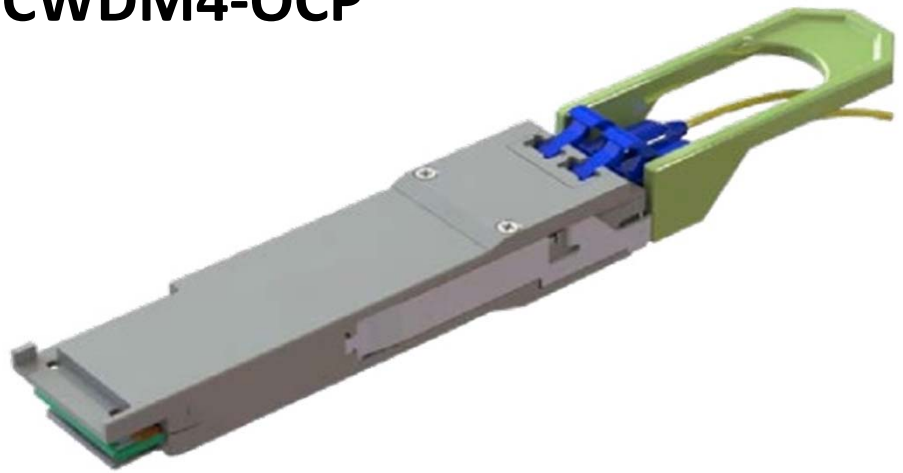
Parameter	Unit	Value
Power budget (at max TDP)	dB	6.2
Operating distance	m	500
Channel insertion loss (max) [a]	dB	3.3
Maximum discrete reflectance [b]	dB	-35
Allocation for penalties (at max TDP) [c]	dB	2.9
Additional insertion loss allowed	dB	0

[a] Channel insertion loss is calculated using the maximum distance specified in Table 3 and cabled optical fiber attenuation of 0.514 dB/km at 1295 nm plus an allocation for connection and splice loss given in 9.2.1.
[b] Per ISO/IEC 11801
[c] Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.

Channel is power limited (not BW limited) - allocation of 3.0dB of total connector insertion loss plus 0.3 dB for fiber attenuation

CWDM4 & CWDM4-OCP

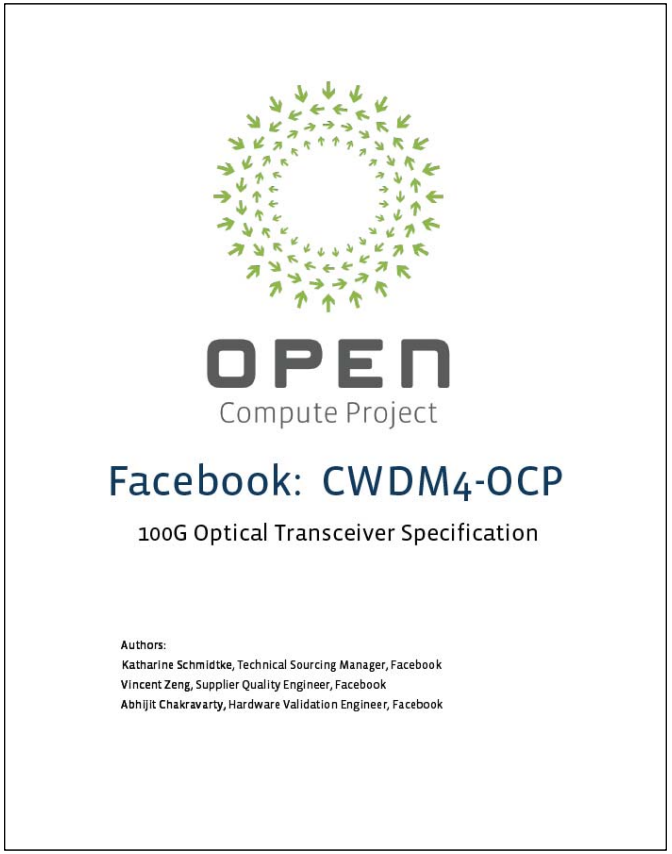
- 100G CWDM4-MSA
  - QSFP-28 form-factor
  - Single-mode duplex fiber
- CWDM4-OCP:
  - Relaxed specification for DCs
  - Reduced temperature range
  - Reduced link budget



	CWDM4-OCP Relaxed Specification	CWDM4 MSA Base Specification
Reach	500 m	2000 m
Link loss	3.5 dB	5 dB
Operating Case Temperature	15-55 deg C	0-70 deg C

CWDM4-OCP version (FaceBook)

100G CWDM4 MSAs


OPEN
Compute Project

Facebook: CWDM4-OCP

100G Optical Transceiver Specification

Authors:
Katharine Schmidtke, Technical Sourcing Manager, Facebook
Vincent Zeng, Supplier Quality Engineer, Facebook
Abhijit Chakravarty, Hardware Validation Engineer, Facebook

CWDM4-OCP channel is power limited (not BW limited) - allocation of 3.2dB of total connector insertion loss plus 0.3 dB for fiber attenuation

	CWDM4-OCP Relaxed Specification	CWDM4 MSA Base Specification
Reach	500 m	2000 m
Link loss	3.5 dB	5 dB
Operating Case Temperature	15-55 deg C	0-70 deg C

100G CWDM4 MSA
Technical Specifications
2km Optical Specifications

Participants

Editor – David Lewis, LUMENTUM
Comment Resolution Administrator – Chris Cole, Finisar

The following companies were members of the CWDM4 MSA at the release of this specification:

Company	Technical Contributors
Avago	John Petrilla
Finisar	Chris Cole, Jonathan King
LUMENTUM	David Lewis
Oclaro	Kiyohisa Hiramoto
Sumitomo Electric	Eddie Tsumura

Contacts: http://cwdm4-msa.org

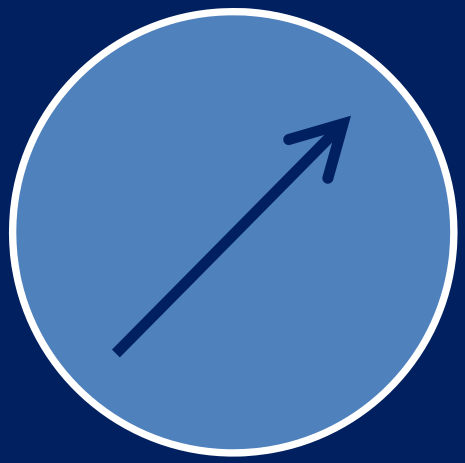
Revisions

Rev	Date	Description
1.0	August 27, 2014	Initial Release
1.1	November 23, 2015	Replace JDSU with Lumentum. Added Section 6 on color coding.

HIGH SPEED MIGRATION OPTIONS

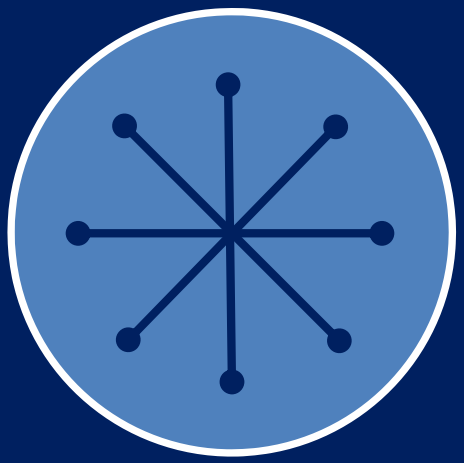
Rodney Casteel RCDD/NTS/OSP/DCDC
CommScope – Sr. Field Application Engineer
Chair – TIA Fiber Optic Technology Consortium

Data Centers undergoing change



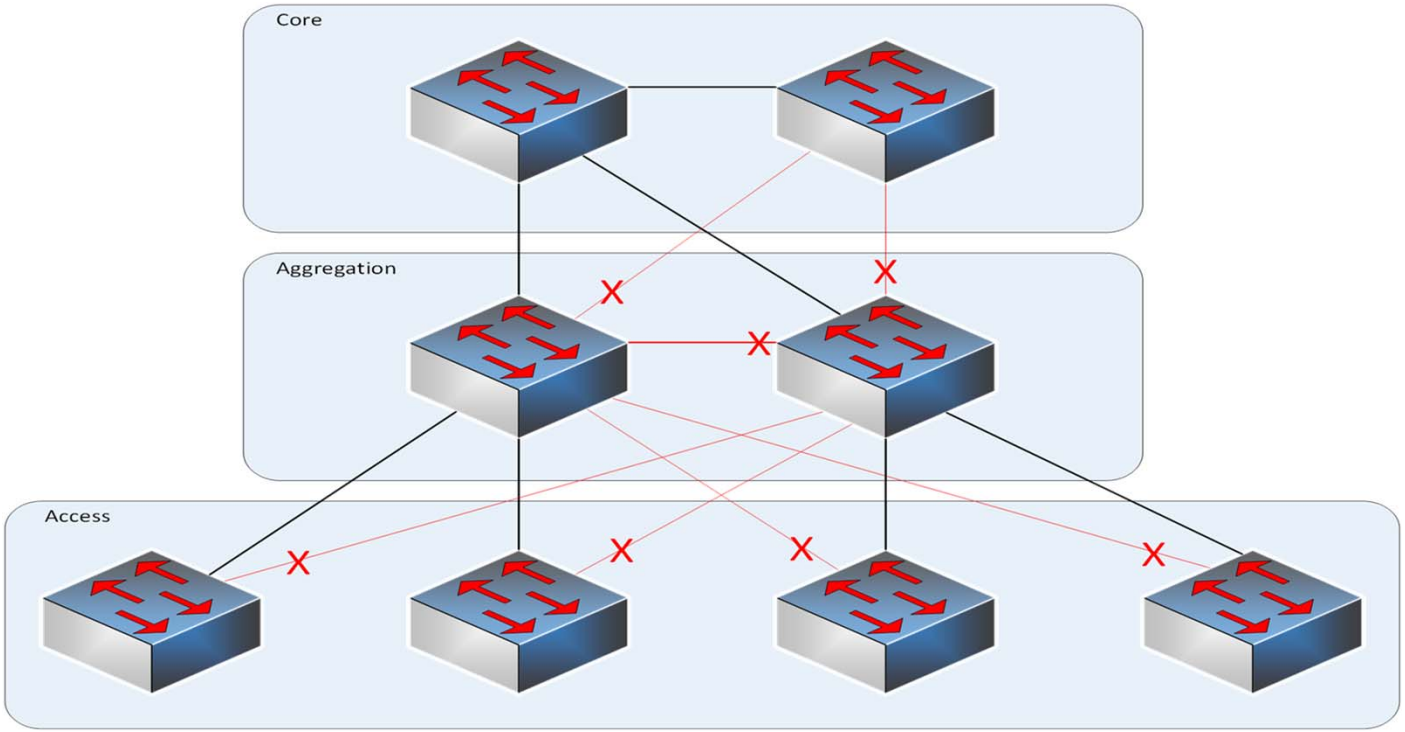
Bandwidth Explosion

Cloud Computing

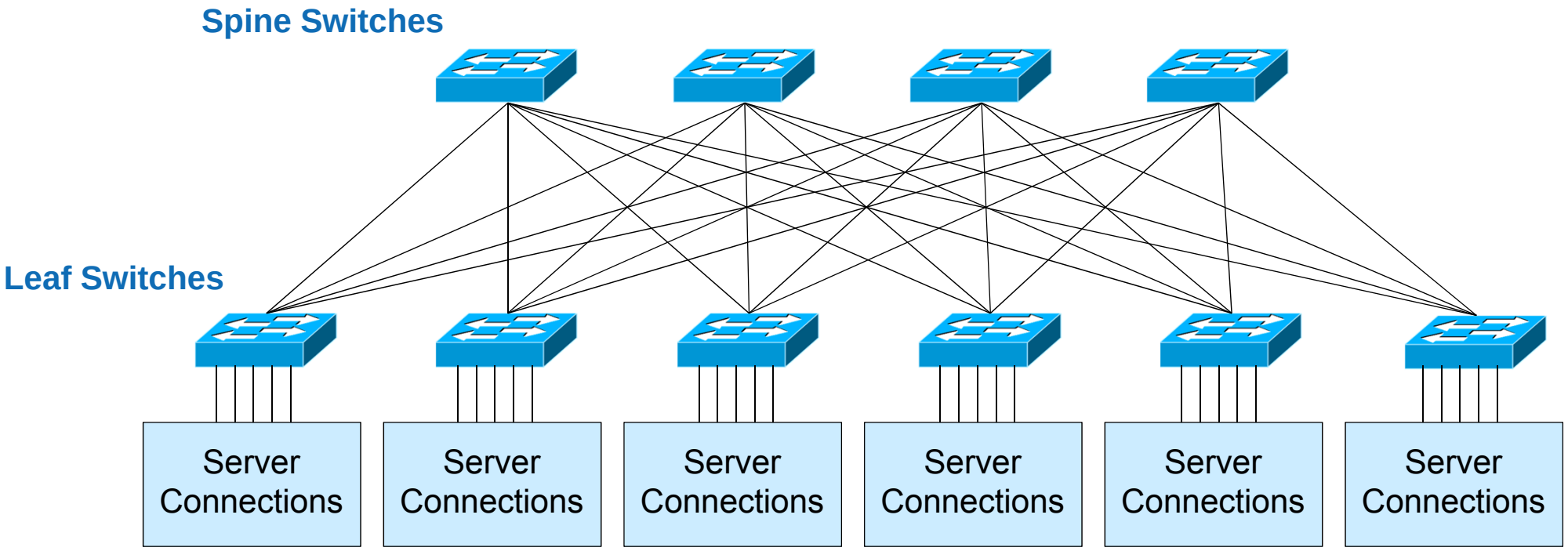


Internet of Things

Data Center Model
Traditional 3-Tier Architecture Model



Data Center Model: Leaf/Spine design



Data Center Model

Two options for cabling infrastructure architecture:

1. Serial Duplex
   - With SM limited by equipment
   - With standard OM 3/4 multimode limited by existing serial transceivers
   - With WBMMF more options for long term higher speed migration
2. Parallel
   - Can be used with SM and MM fiber
   - Can be used with WBMMF
   - Requires more fibers

COMMSCOPE®


High Speed Migration
your data center - beyond the now


2017 BICSI Fall
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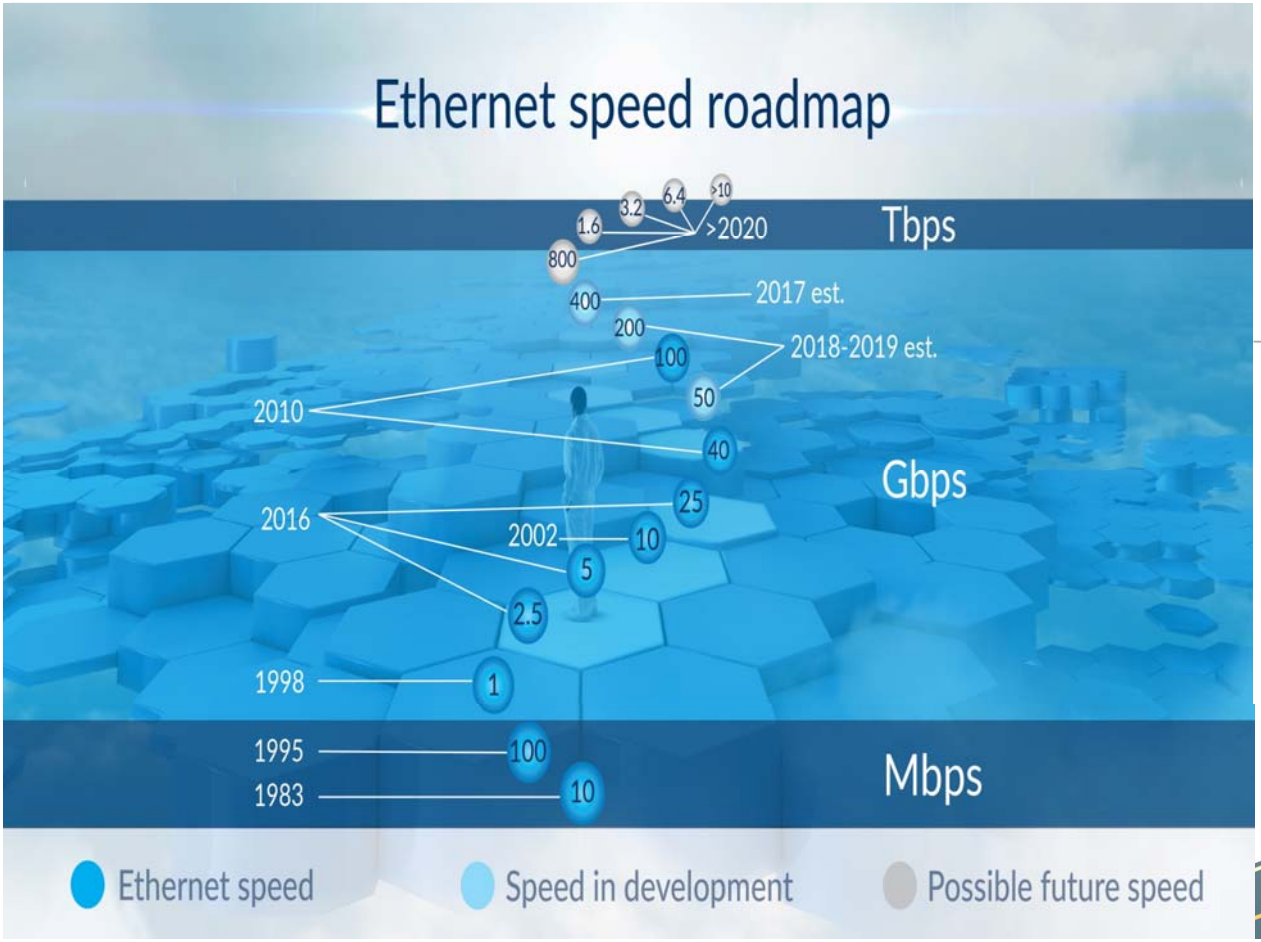
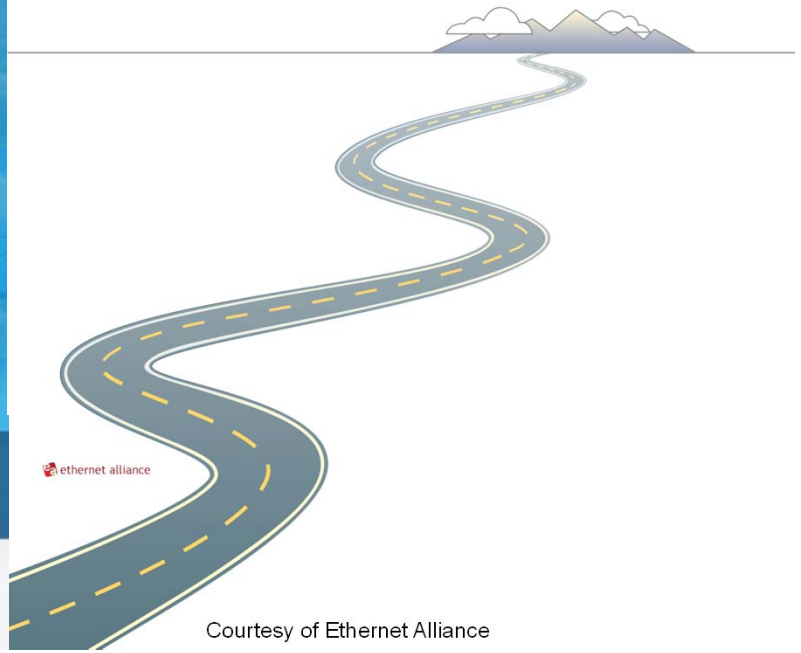
SEPTEMBER 24-28 | LAS VEGAS, NV

WHAT IS HIGH SPEED ?



How does your roadmap compare?



Courtesy of Ethernet Alliance

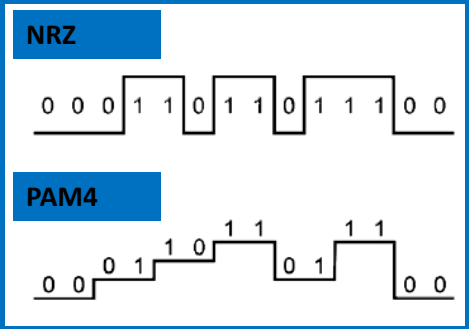
Application	Standard	Fiber	Rated Reach	Max. Channel Loss at Rated Reach (dB)	Connection and Splice Loss Allocation at Rated Reach (dB)
10-Gigabit Ethernet	10GBASE-SR	MM	400 m (OM4)	2.9	1.5
	10GBASE-LX4	MM	300 m	2.0	1.5
	10GBASE-LRM	MM	220 m	0.4	1.5
	10GBASE-LR	SM	10 km	6.0	2.0
	10GBASE-ER	SM	40 km	11.0	2.0
25-Gigabit Ethernet	25GBASE-SR	MM	100 m (OM4)	1.9	1.5
	25GBASE-LR	SM	10 km	6.3	2.0
	25GBASE-ER	SM	40 km	18.0	2.0
40-Gigabit Ethernet	40GBASE-SR4	MM	150 m (OM4)	1.5	1.0
	40GBASE-FR	SM	2 km	4.0	3.0
	40GBASE-LR4	SM	10 km	6.7	2.0
	40GBASE-ER4	SM	40 km	18.5	2.0
50-Gigabit Ethernet	50GBASE-SR	MM	100 m (OM4)	1.9	1.5
	50GBASE-FR	SM	2 km	4.0	3.0
	50GBASE-LR	SM	10 km	6.3	2.0
100-Gigabit Ethernet	100GBASE-SR10	MM	150 m (OM4)	1.5	1.0
	100GBASE-SR4	MM	100 m (OM4)	1.9	1.5
	100GBASE-SR2	MM	100 m (OM4)	1.9	1.5
	100GBASE-DR	SM	500 m	2.6 to 3.0 depending on discrete reflectance	2.35 to 2.75 depending on discrete reflectance
	100GBASE-LR4	SM	10 km	6.3	2.0
	100GBASE-ER4	SM	40 km	18.0	2.0

COMMSCOPE®

Application	Standard	Fiber	Rated Reach	Max. Channel Loss at Rated Reach (dB)	Connection and Splice Loss Allocation at Rated Reach (dB)
200-Gigabit Ethernet	200GBASE-SR4	MM	100 m (OM4)	1.9	1.5
	200GBASE-DR4	SM	500 m	3.0	2.75
	200GBASE-FR4	SM	2 km	4.0	3.0
	200GBASE-LR4	SM	10 km	6.3	2.0
400-Gigabit Ethernet	400GBASE-SR16	MM	100 m (OM4)	1.9	1.5
	400GBASE-DR4	SM	500 m	3.0	2.75
	400GBASE-FR8	SM	2 km	4.0	3.0
	400GBASE-LR8	SM	10 km	6.3	2.0
	40G-BDi	MM	200 m (OM5)	1.4	0.8
	40G-SWDM4	MM	440 m (OM5)	3.3	2.0
	100G-SWDM4	MM	150 m (OM5)	1.8	1.4
	3200-M5-SN-S	MM	20 m (OM2)	2.0	1.5
	3200-M5E-SN-S	MM	70 m (OM3)	1.9	1.5
	3200-M5F-SN-I	MM	100 m (OM4)	1.9	1.5
	3200-SM-LC-L	SM	10 km	6.3	2.0
	128GFC-SW4	MM	100 m (OM4)	1.4	1.0
	128GFC-PSM4	SM	500 m	3.0	2.75
	128GFC-CWDM4	SM	2 km	4.1	3.0
	64GFC	MM			
	64GFC	SM			
	256GFC	MM			
	256GFC	SM			
	100G-PSM4	SM	500 m	3.3	3.0
	100G-CDWM4	SM	2 km	5.0	3.9
	100G-LRL4	SM	2 km	4.0	3.0

Technologies Enabling Higher Capacity per Fiber

PAM4
More Efficient Modulation

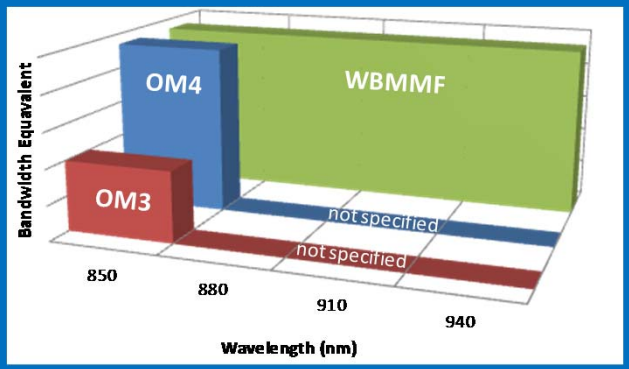


Enabling 50Gb per lane

SWDM
More Efficient Fiber Usage

Enabling 4 λ per fiber

WBMMF
More Efficient Fiber

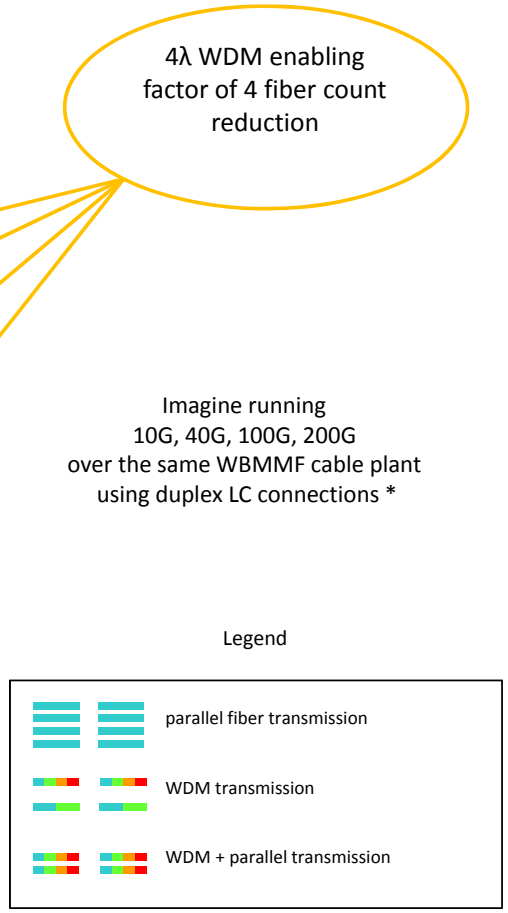


Supporting 4 λ per fiber to practical distances

Higher Speed Strategies

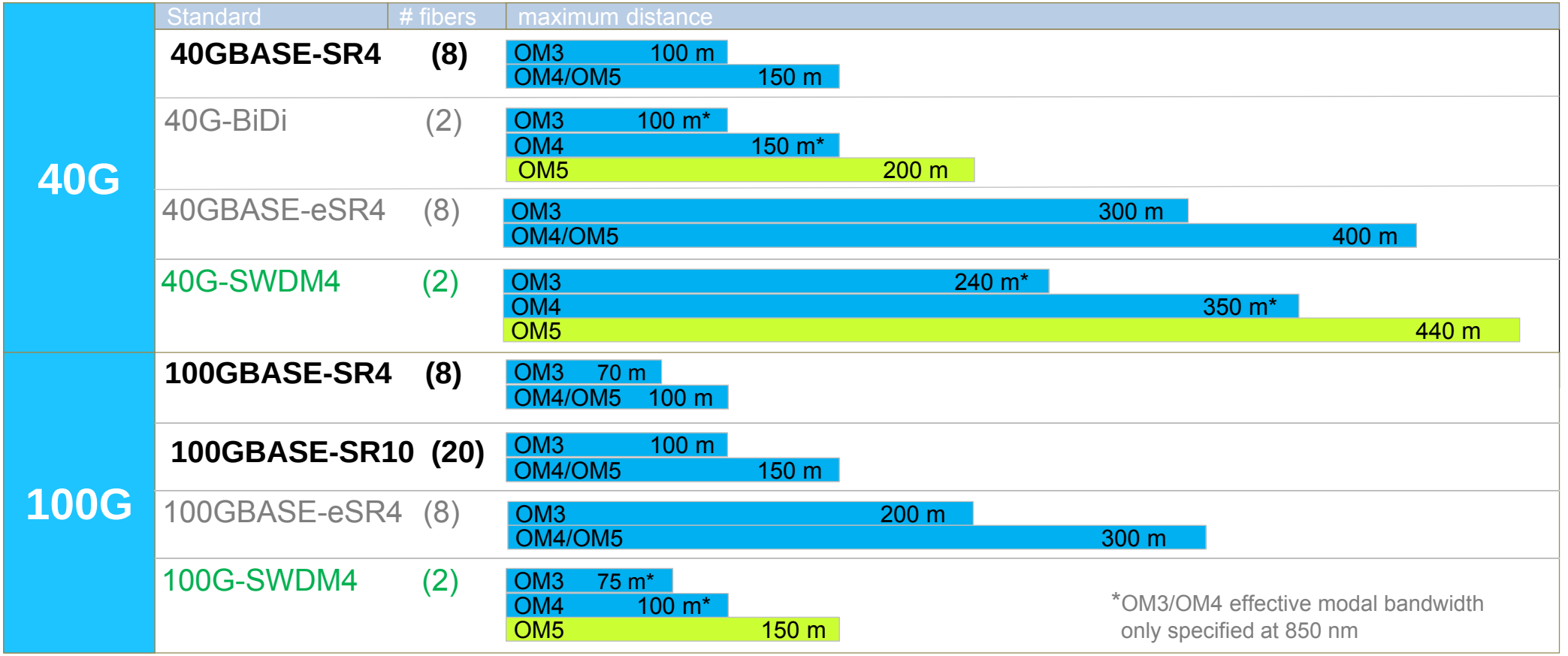
Data Rate	10G NRZ Parallel TX RX	25G NRZ Parallel TX RX	50G PAM4 Parallel TX RX	10, 25, 50G WDM & Parallel TX RX
40G		N/A	N/A	
100G				
200G				
400G				

*Parallel fibers remain essential to support break-out functionality



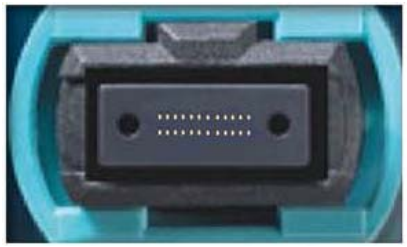
40G/100G Applications and Multimode Fiber

Maximum reach based on Standards, MSAs and/or vendor specifications



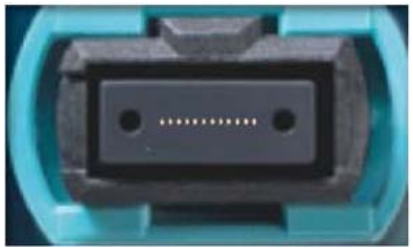
"In addition to supporting the same 850nm and 1300nm applications as OM4, *OM5 provides advantage in the support of future applications using WDM in the wavelength range 850nm to 953nm*" *(FDIS ISO/IEC 11801-1)*

MPO Options



24 FIBER

- HIGHER DENSITY
- FEWER COMPONENTS
- MORE COST EFFECTIVE



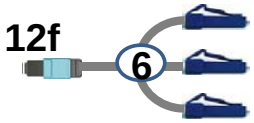
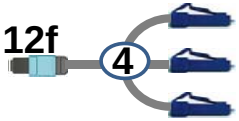
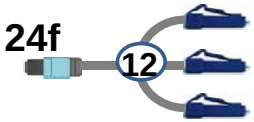
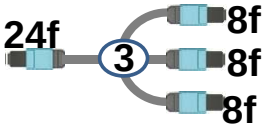
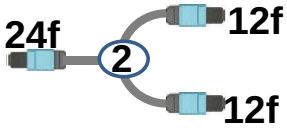
12 FIBER

- GLOBALLY RECOGNIZED STANDARD
- LARGE EMBEDDED BASE
- SUPPORTS MULTIPLE POLARITY SCHEMES

8 FIBER

- SAME AS 12 EXCEPT ONLY USES 8 FIBERS
- NOT REALLY A STANDARDS RECOGNIZED INTERFACE
- USED MOSTLY FOR –SR4 APPLICATIONS

Array Connectivity = Application Support Flexibility

multiple 2-fiber applications on 12f cabling	MPO 12 active fibers		6 x duplex LC
40G-SR4 breakout to 10G-SR	MPO 8 active fibers		4 x duplex LC
120Gb/s breakout to 10G-SR	MPO 24 active fibers		12 x duplex LC
120Gb/s breakout to 40G-SR4	MPO 24 active fibers		3 x MPO 8 active fibers each
100G-SR10 on 12f cabling	MPO 20 active fibers		2 x MPO 10 active fibers each

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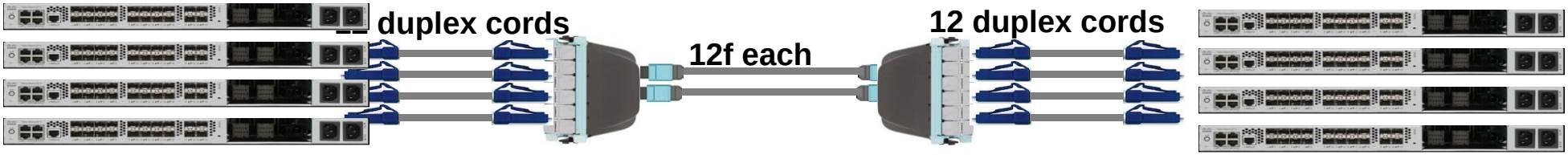
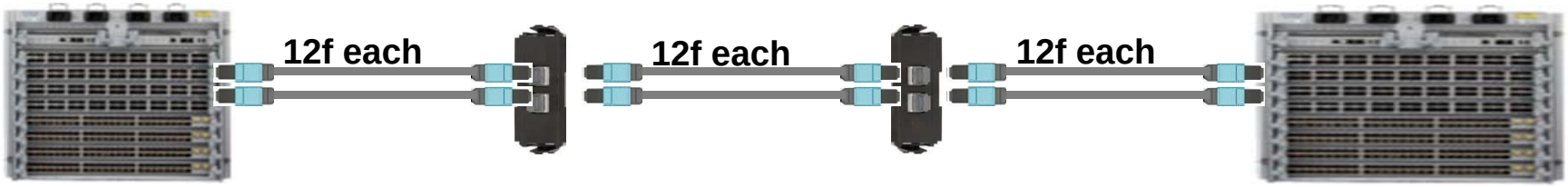
Cabling Infrastructure Migration from 10G to 40G

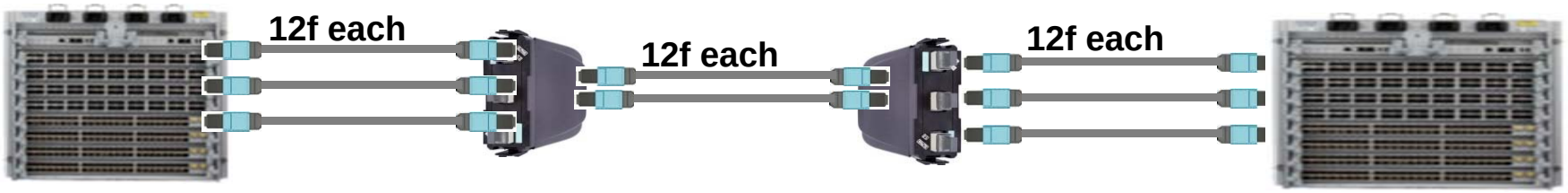
Existing 10G Connections using MPO trunk cabling



Migration to (2) 40G connections while retaining existing MPO cabling



Migration to (3) 40G connections while retaining existing MPO cabling with 100% fiber utilization in trunk cables



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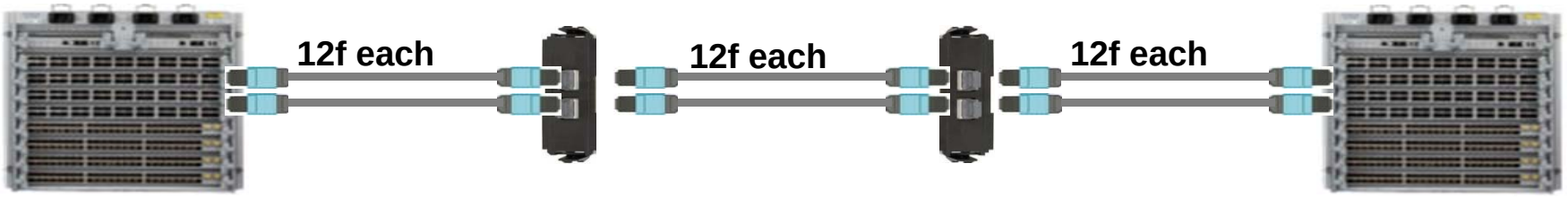
Cabling Infrastructure Migration from 10G to 40G

Existing (2) 40G connections using MPO cabling



Migration to 100G connection while retaining existing MPO trunk cabling and adapter panels

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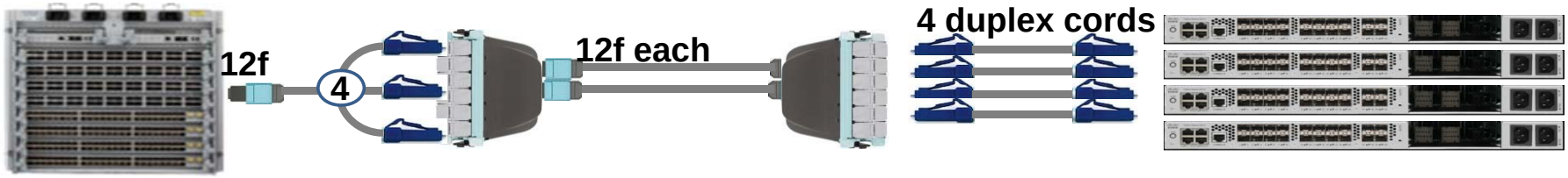
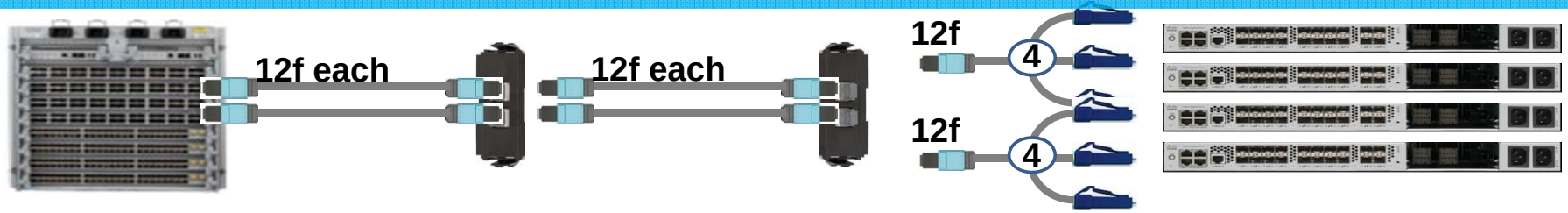
Cabling Infrastructure Breakout of 10G from 40G

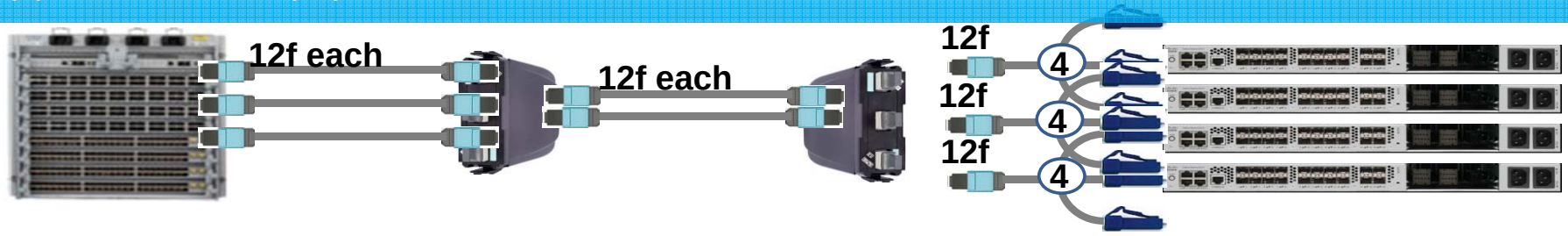
40G breakout to (4) 10G LC using existing 10G cabling



(2) 40G breakout to (8) 10G LC

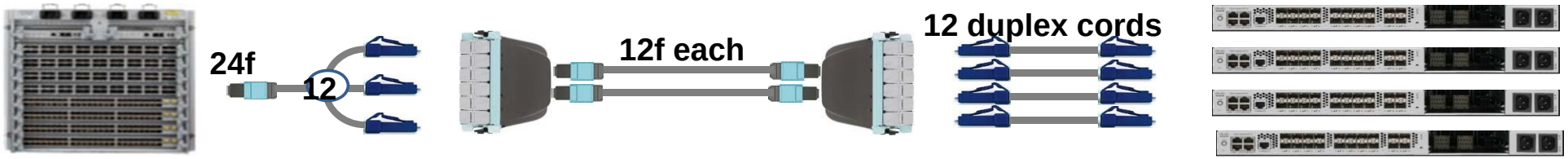


(3) 40G breakout to (12) 10G LC with 100% fiber utilization in trunk cables



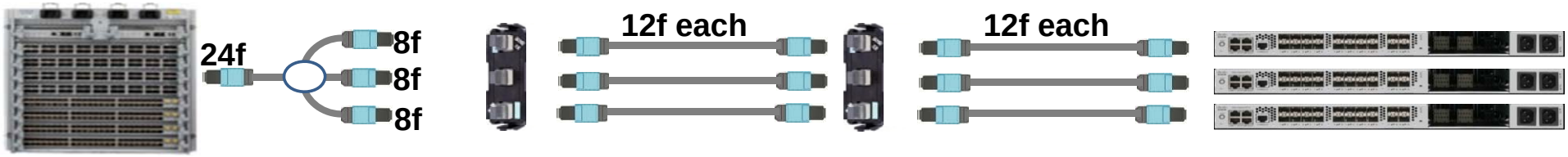
Cabling Infrastructure Breakout of 10G from 100G/120G

120G MPO to (12) 10G LC with individual 10G circuit routing granularity

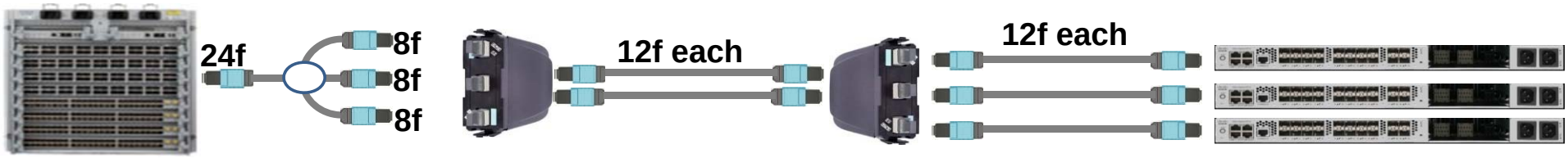


Cabling Infrastructure Breakout of 40G from 100G/120G

120G MPO breakout to (3) 40G MPO

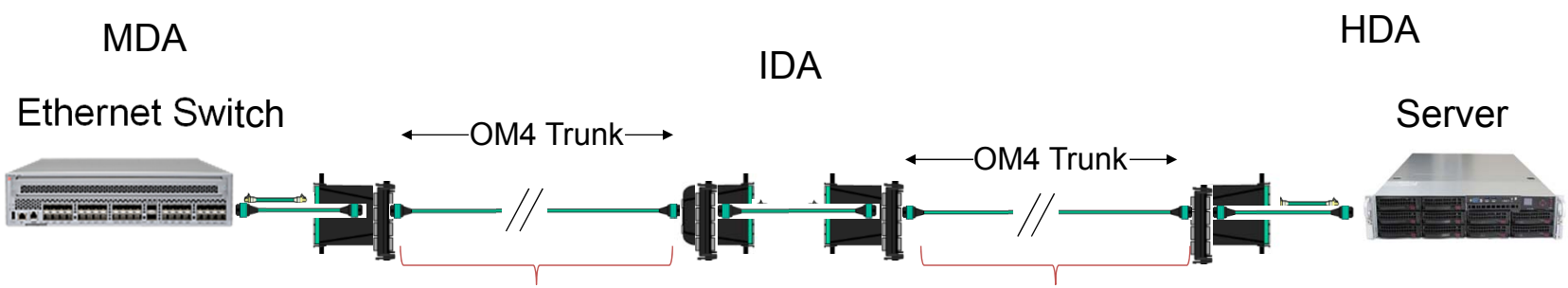


120G MPO breakout to (3) 40G MPO with 100% fiber utilization in trunk cables



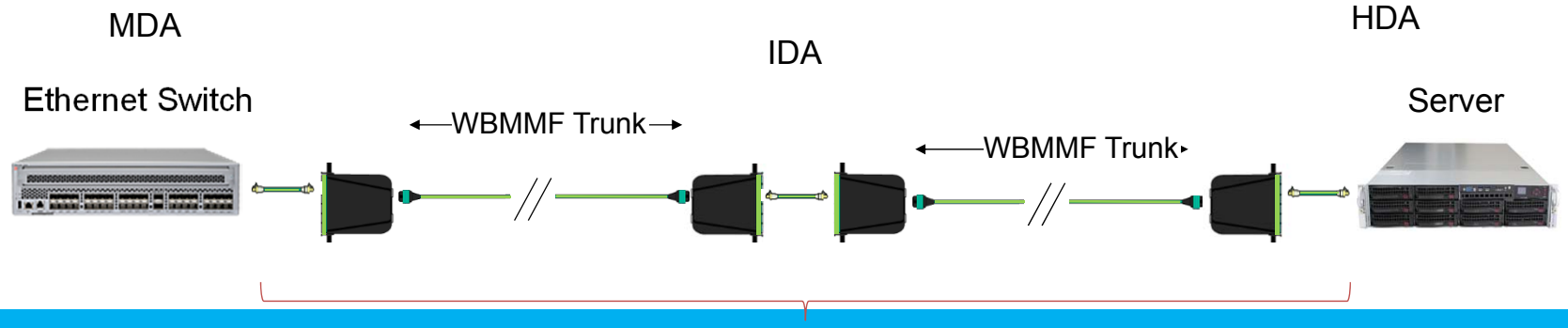
Migration from 10G to 100G with –SR4 and OM4

100GBASE-SR4



Trunk cabling is retained

Migration from 10G to 100G with –SR4 and OM5



All cabling is retained

SUMMARY

Two options for cabling infrastructure architecture:

1. Serial Duplex
2. Parallel

Three options for MPO interface

1. 8 fiber
2. 12 fiber
3. 24 fiber

Many options for Migration Path

1. OM3/OM4
2. OM5
3. SM

The Fabulous, Fast Moving, Fever Pitch, Forever Accelerating Fiber Frenzy

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