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

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Tony Irujo - OFS
Darryl Heckle - Corning
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 24 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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IEEE Standards Update

PAUL NEVEUX, Jr., Ph.D.

Director, Premises Optical Fiber / OEM Market Management
Superior Essex International, LP

IEEE Copper Standards

New IEEE Twisted Pair Standards

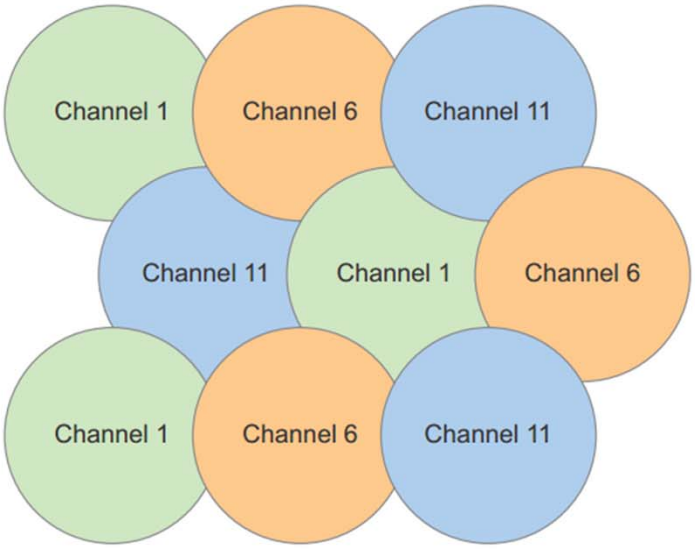
- IEEE 802.3bz: 2.5/5 Gb Ethernet
  - At least 100 meters over CAT 6; less for Cat 5e: Alien X-talk
  - Applications include Wi-Fi and PoE++
  - Side Benefit: Currently, all desktop/laptops have 1Gb Ethernet built in will allow manufacturers to offer faster wired speeds to desktop/laptop by building in 2.5/5 G instead
- IEEE P802.3bq: 25/40 Gb Ethernet over twisted pair copper
  - Requires CAT 8 shielded twisted pair cable
  - Published June 2016

IEEE Mobile and Wireless

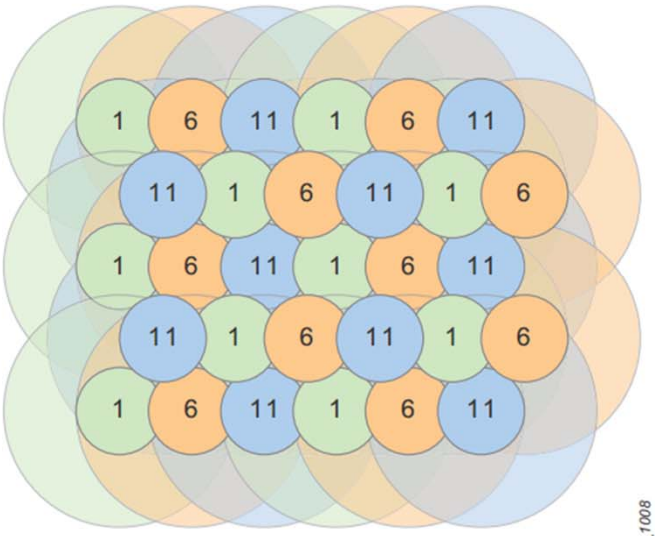
Current Wireless Standards

Wireless Standard	Data Rate (Mb/s)
802.11	2
802.11b	11
802.11a,g	54
802.11n	600
802.11ac	1300
802.11ac (Wave 2)	6900

IEEE 802.11ac



Coverage design with 7.2 Mb/s cell edge



Capacity design with 216.7 Mb/s cell edge

Source: Aruba

Wireless Standards in Development

Wireless Standard	Task Group Name	Data Rate (Gb/s)	Expected Publication Date
802.11ax	High Efficiency (HE) Wireless LAN	10	December 2019
802.11ay	Enhanced Throughput for Operation in License-Exempt Bands above 45 GHz	20	November 2019
802.11az	Next Generation Positioning (NGP)	N/A	1Q 2022
802.11ba	Wake-up Radio (WUR) Operation	N/A	2Q 2018

IEEE 802.11ax: High Efficiency Wireless

Parameter	802.11ac	802.11ax
Bands	5 Hz	**2.4** and 5 Ghz
Channel Bandwidth	20, 40, 80, 80+80 & 160 MHz	20, 40, 80, 80+80 & 160 MHz
FFT Size	64, 128, 256, 512	128, 256, 512, **1024**, **2048**
Subcarrier Spacing	312.5 kHz	**78.125 kHz**
OFDM Symbol Duration	3.2 µs + 0.8/0.4 µs CP	**12.8** µs + 0.8/**1.6/3.2** µs CP
Highest Modulation	256-QAM	**1024-QAM**
Data Rates	433 <bps (80 MHz, 1 SS) 6933 Mbps (160 MHz, 8 SS)	**600.4 <bps (80 MHz, 1 SS)** **9607.8 Mbps (160 MHz, 8 SS)**

802.11ay Wireless above 45 GHz

- Environment
  - Crowded public spaces (airports, malls, etc.)
  - Link distance up to 10 cm to 1 km with line of sight (distance affects speed)
  - Devices stationary during use; one device per WAN

- Application
  - Mass data downloads (video, pictures, etc.)
  - Jitter not critical – key metric is user's transfer time: < 1 second
  - Application exits once task is complete

Fiber Required for Aggregation

- New copper and wireless applications will require larger “pipes” to backhaul information to the data center
- The new bottleneck will be from the telecom closet to the data center unless higher throughput media, like fiber, are used.
- All these new applications will require higher throughputs in the data center.

Optical Fiber Ethernet Update

IEEE Standards

10, 40 and 100 Gb Ethernet on MMF

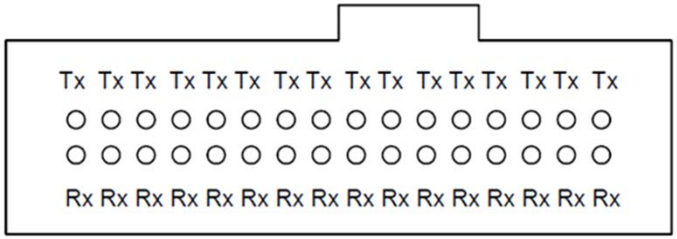
Ethernet Speed	IEEE	Designation	Fiber Type	Number of Fibers	Maximum Link Length (m)	Maximum Channel Insertion Loss (dB)
10 Gb	802.3ae	10GBASE-SR	OM3	2	300	2.6
40 Gb	802.3ba	40GBASE-SR4	OM3	8	100	1.9
40 Gb	802.3ba	40GBASE-SR4	OM4	8	150	1.5
100 Gb	802.3ba	100GBASE-SR10	OM3	20	100	1.9
100 Gb	802.3ba	100GBASE-SR10	OM4	20	150	1.5
100 Gb	802.3bm	100GBASE-SR4	OM4	8	100	1.9

40 and 100 Gb Ethernet on SMF

Ethernet Speed	IEEE	Designation	Wave-lengths (nm)	Number of Fibers	Max. Link Length	Max. Channel Insertion Loss (dB)
40 Gb	802.3ba	40GBASE-IR4	4 λ 1260 to 1355	2	2 km	4.0
40 Gb	802.3ba	40GBASE-LR4	4 λ 1260 to 1355	2	10 km	6.7
100 Gb	802.3ba	100GBASE-LR4	4 λ 1260 to 1355	2	10 km	6.3

IEEE 802.3bs – 200/400 Gb/s Ethernet

- Implementation for MMF:
  - 16 x 25 Gb/s (32 fibers)
- Full duplex operation
- Media Distances
  - 100 m over OM4/5 MMF
  - 70 m over OM3 MMF
  - 10 km, 2 km, 500 m over SMF
- Expected Jan 2018 Publication



IEEE 802.3cd -
50 Gb/s (Single Lane), NG 100/200 Gb/s Ethernet

- 50 Gb/s Ethernet PHYs
  - MMF with lengths up to at least 100 m (OM4/5; 50GBASE-SR)
  - SMF with lengths up to at least 2 km and lengths up to at least 10 km
- 100 Gb/s Ethernet PHYs
  - MMF with lengths up to at least 100 m (OM4/5; 100GBASE-SR2)
  - Duplex SMF with lengths up to at least 500 m
- 200 Gb/s Ethernet PHYs
  - MMF with lengths up to at least 100 m (OM4/5; 200GBASE-SR4)

New IEEE Study Group

- 200/400G Ethernet over OM3/4/5 Fiber
- 4 Wavelengths over at least 100 meters using OM5 Fiber
- Reach for OM3/4 to be determined
- Actual objectives still to be determined

IEEE P802.3ca 100G-EPON Task Force

- Support subscriber access networks using point to multipoint topologies on optical fiber
- Provide specifications for physical layers operating over a single SMF strand and supporting symmetric and/or asymmetric MAC data rates of:
  - 25 Gb/s in downstream and less than or equal to 25 Gb/s in upstream
  - 50 Gb/s in downstream and less than or equal to 50 Gb/s in upstream
  - 100 Gb/s in downstream and less than or equal to 100 Gb/s in upstream
- Support coexistence with 10G-EPON
- Optical power budgets to accommodate channel insertion losses equivalent to those supported by the 10G-EPON standard
- Wavelength allocation allowing concurrent operation with 10G-EPON PHYs
- Wavelength allocation allowing concurrent operation of 25G-EPON and G-PON reduced wavelength set (1290nm-1330nm) PHYs

IEEE P802.3cc 25 Gb/s Ethernet over SMF

- Provide physical layer specification which support 25 Gb/s operation over at least 10 km on (duplex) SMF.
- Provide physical layer specification which support 25 Gb/s operation over at least 40 km on (duplex) SMF.
- Provide appropriate support for OTN
- Target market is campus, WAN, and MANs
- Approved as a standard on December 6, 2017

TIA Standards Update

Cindy Montstream, EE, RCDD/NTS, CPLP

Director of Technology Support & Training
Data Communications Division, Legrand

Chair, TIA TR-42.3
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.

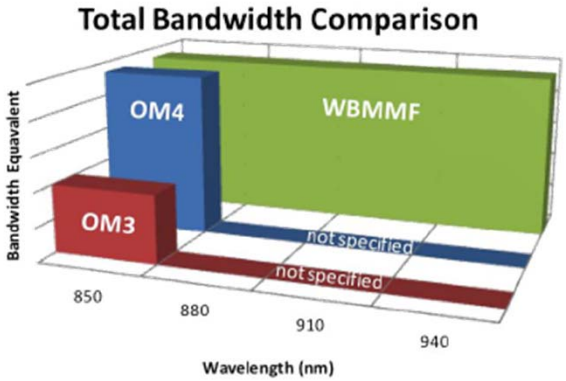
New Media Types & Connector

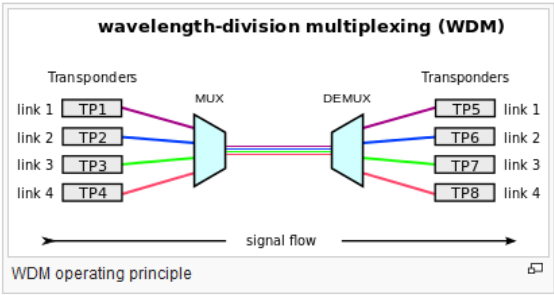
New fiber type

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

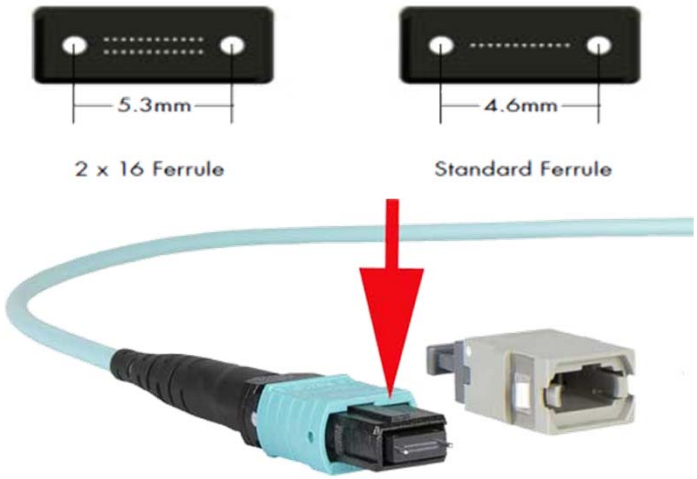




WDM operating principle

ANSI/TIA-604-18 (FOCIS 18)

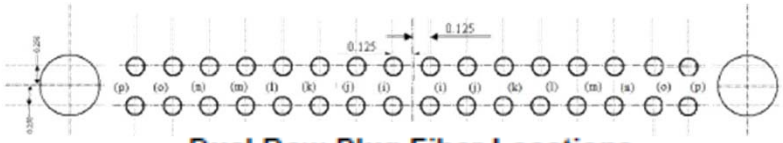
- 1x16 and 2x16 Multifiber Push-On connector
  - Has offset key
- 1x16 is similar to 12-fiber MPO & 2x16 similar to 24-fiber MPO (FOCIS 5)
    - Requires new FOCIS document because connector requires different distance between guide holes
- Supports 1st generation of 400 GbE over MMF



16 Fibers

Single Row Plug Fiber Locations

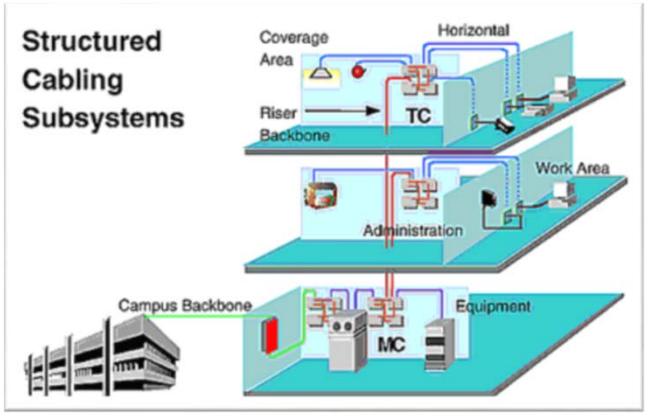
32 Fibers



Dual Row Plug Fiber Locations

Standards Integrating New Media Types

- ANSI/TIA-568.0-D Addendum 1
  (Generic Telecommunication Cabling)
  - 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
- ANSI/TIA-568.1-D Addendum 1
  (Commercial Building Telecommunication Cabling)
- ANSI/TIA-1179-A (Healthcare)
  - OM4 is minimum MMF recommended
  - Min 2 fiber backbones
  - Array connectors



Standards Integrating New Media Types

- ANSI/TIA-942-B (Datacenter)
  - Cabinets should be at least 48” deep & wider than 24”
  - Max length for direct attach cables in EDA – 7m (were 10m)
    - Direct attach cabling between rows is not recommended
  - Added MPO-16 / 32 & MPO-24
  - Recommends pre-terminated cabling

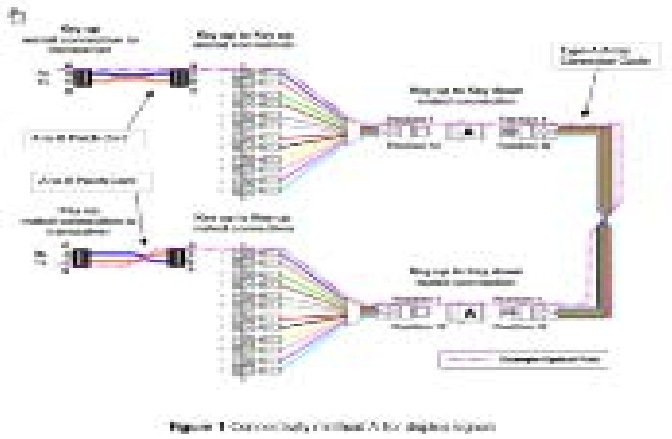
- ANSI/TIA-862-B Addendum 1 (Intelligent Building)
  - 2 fiber minimum

- ANSI/TIA-4966 Addendum 1 (Education)
  - OM4 or OM5

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 are 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

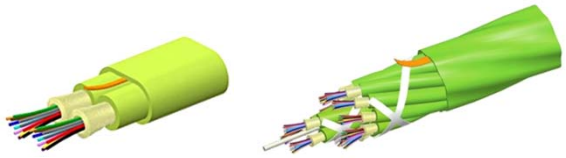
In Process & New Work

Optical Fibers and Cables

- Ongoing work:
- Revising TIA-598D
  - Addendum 1: Specs for colors 13-16
    - TG formed for round robin on color measurement for colors 13-16;
    - 2nd industry ballot
  - Addendum 2: Jacket color for WBMMF
    - Approval of Lime for jacket color for OM5 fiber applications.

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

Table 11 - Test cord loss allowance

Mated termination combination	Multimode (dB/connection)	Single-mode (dB/connection)
Reference-grade to standard-grade	0.3[1]	0.5[2]
Standard-grade to standard-grade	0.75	0.75

Note 1 – This value is taken from ANSI/TIA-526-14, Table F.1.
Note 2 – This value is taken from ANSI/TIA-526-7, Table G.1.

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

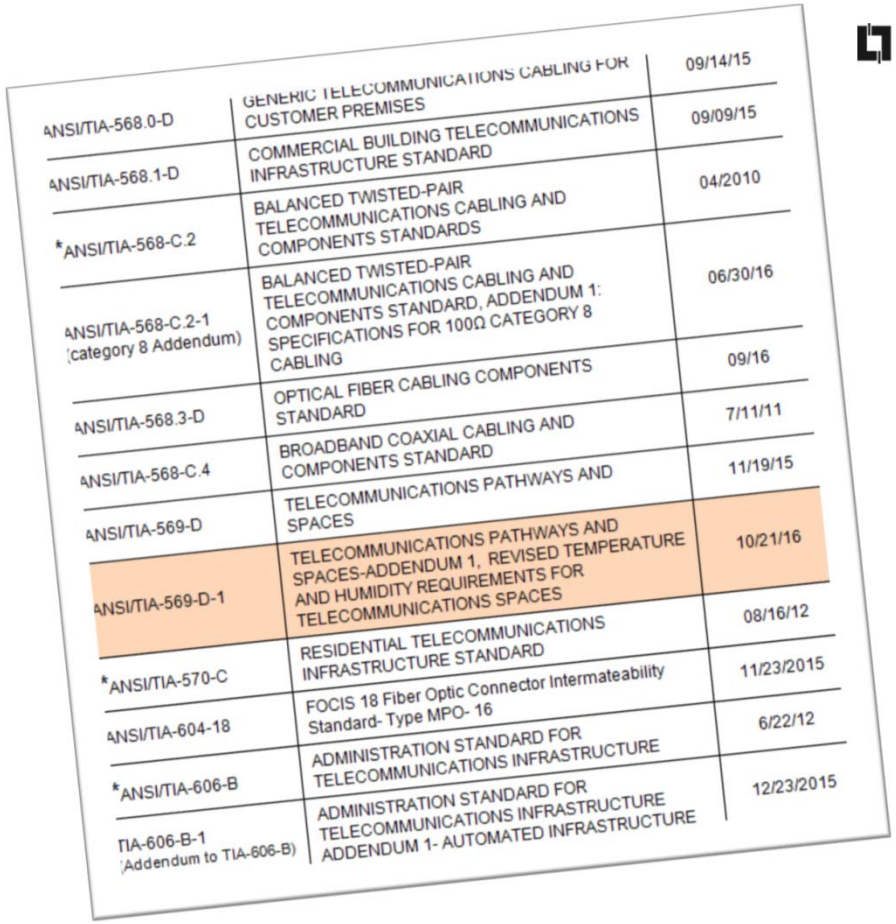
- Places of Assembly Task Group
  - Working on potential standard for Airports, Stadiums, Theaters, etc.

Additional Information Available

FOTC Website

Summary of current TIA standards

http://www.tiafotc.org



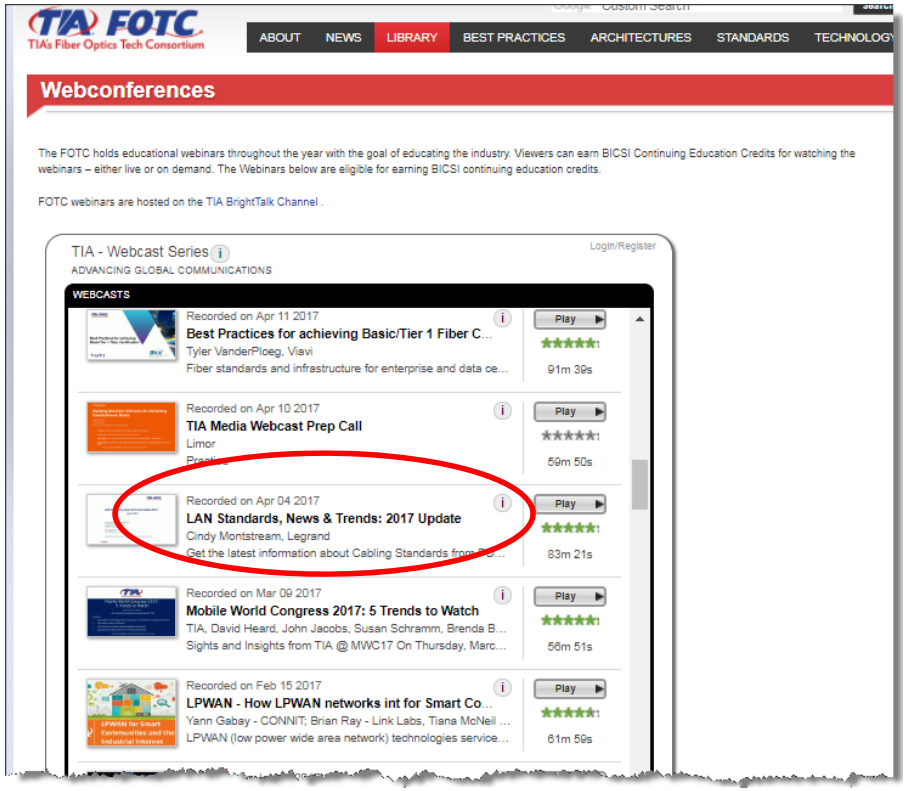
ANSI/TIA-568.0-D	GENERIC TELECOMMUNICATIONS CABLING FOR CUSTOMER PREMISES	09/14/15
ANSI/TIA-568.1-D	COMMERCIAL BUILDING TELECOMMUNICATIONS INFRASTRUCTURE STANDARD	09/09/15
*ANSI/TIA-568-C.2	BALANCED TWISTED-PAIR TELECOMMUNICATIONS CABLING AND COMPONENTS STANDARDS	04/2010
ANSI/TIA-568-C.2-1 (category 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



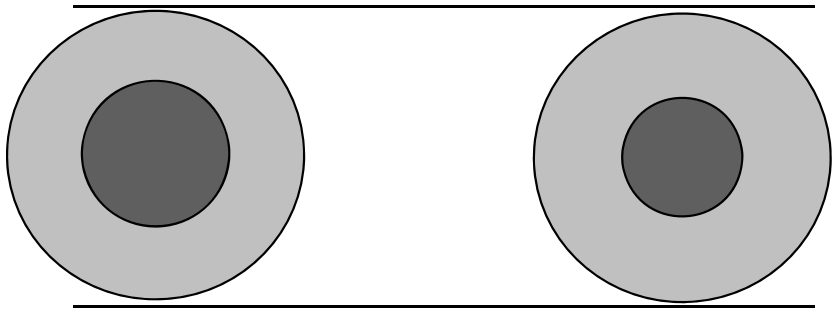
Optical Fiber Technology

Tony Irujo
Sales Engineer
OFS

Two Basic Optical Fiber Types

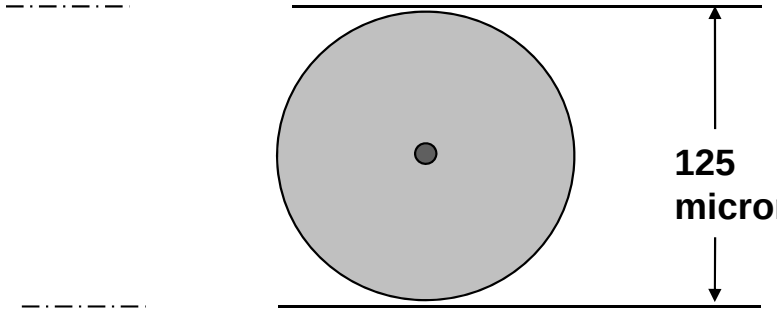
1. Multimode

62.5 micron 50 micron



2. Singlemode

~8 micron



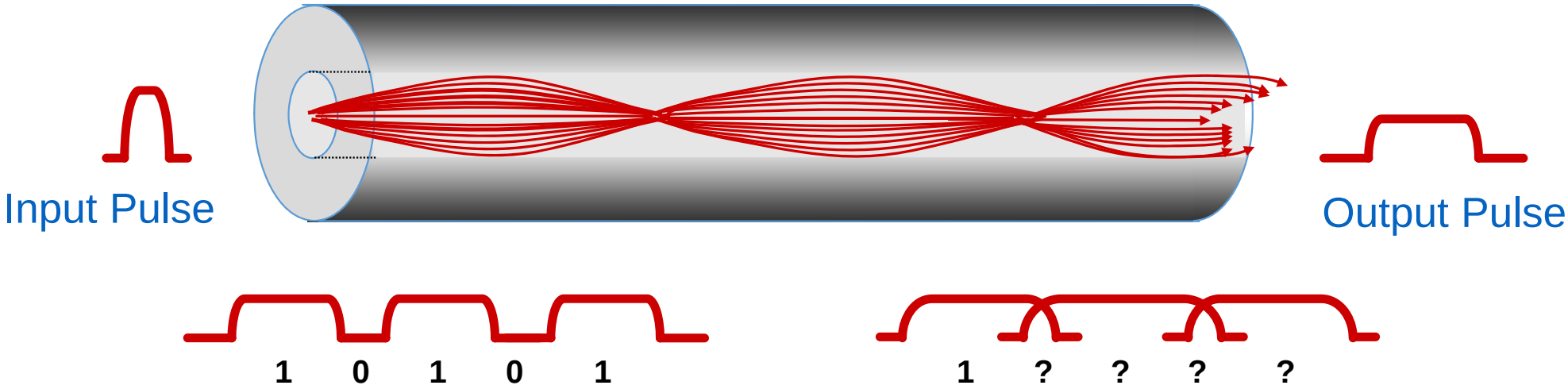
850 nm &
some 1300 nm

Operating Wavelengths

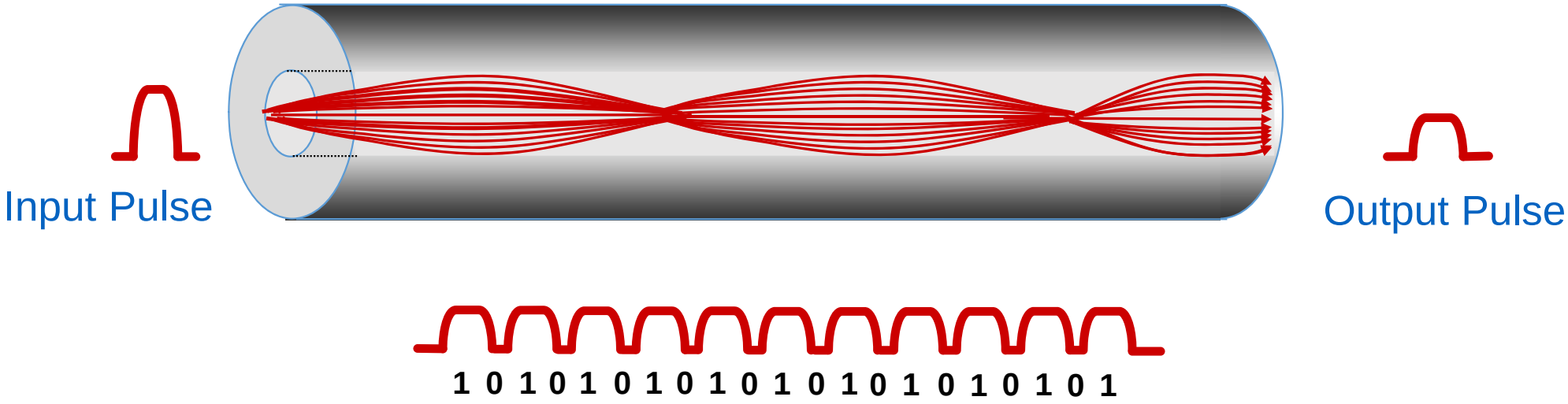
1310 - 1625 nm

Multimode Fiber

- Light Signal travels along many paths
- Pulse spreading occurs due to **Modal Dispersion** or **Differential Mode Delay** (DMD)
- Pulse spreading limits **Bandwidth**



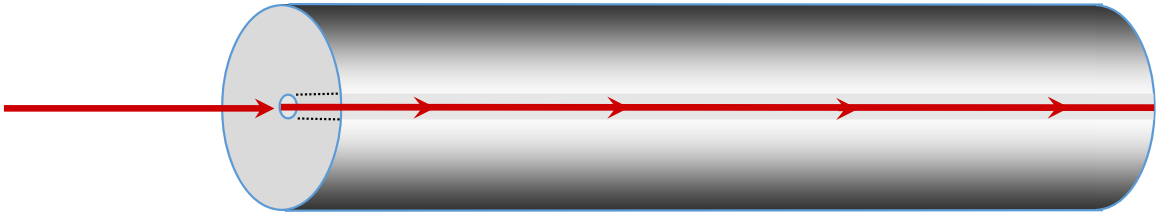
Modal Dispersion / DMD Minimized in OM3 and especially OM4 MM Fiber



Singlemode Fiber

Small core guides only one mode

- Eliminates modal dispersion.
- Enables tremendous transmission capacity over very long distances.

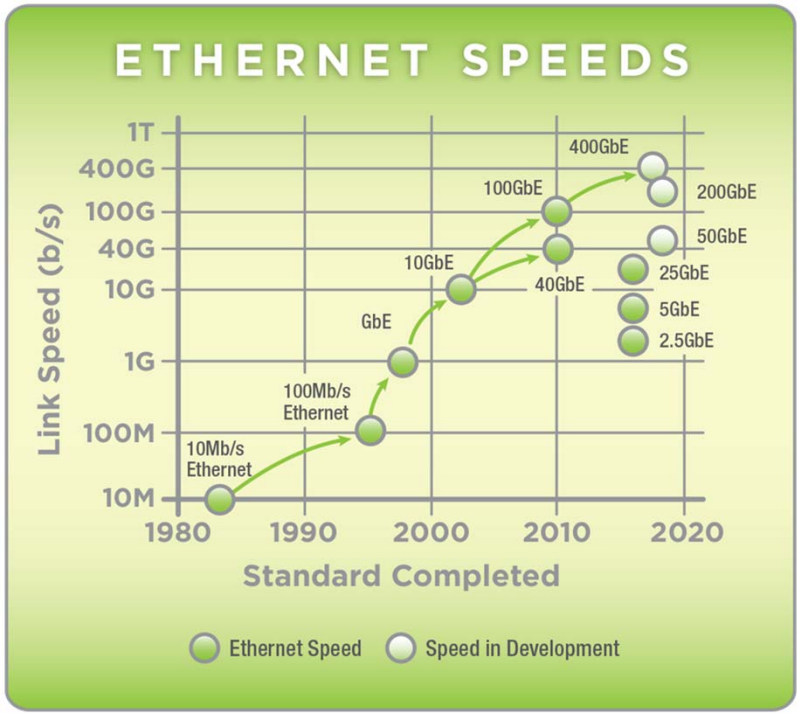


Multimode or Singlemode? Speed, Reach, Cost…

- From 10G to 100G and beyond, Multimode fiber supports reaches in the **~100 to 600 meter** range (~300 to 2000 ft), depending on fiber type used (OM3, OM4, OM5), as well as transceiver type.
- Beyond 500 – 600 meter range, Singlemode fiber is necessary.

Generally, the total installed cost of a Multimode system continues to be less expensive than that of a Singlemode system, due to cost of the optics.

Keeping up with Rising Data Rates



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

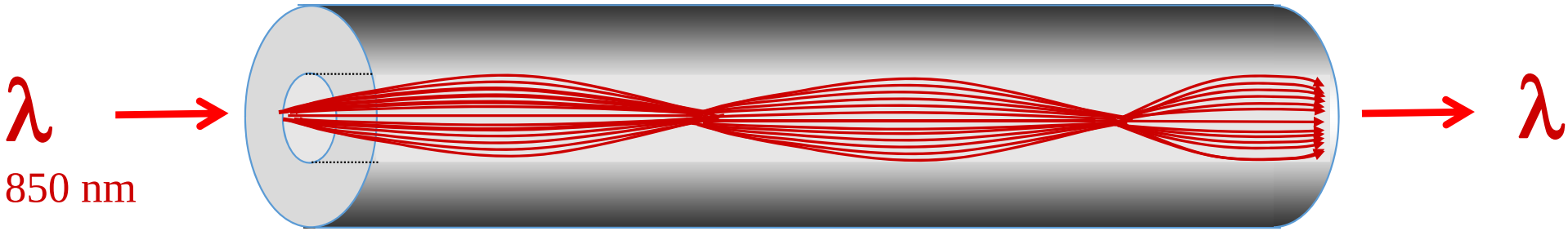
ethernet alliance

Fiber is up to the task

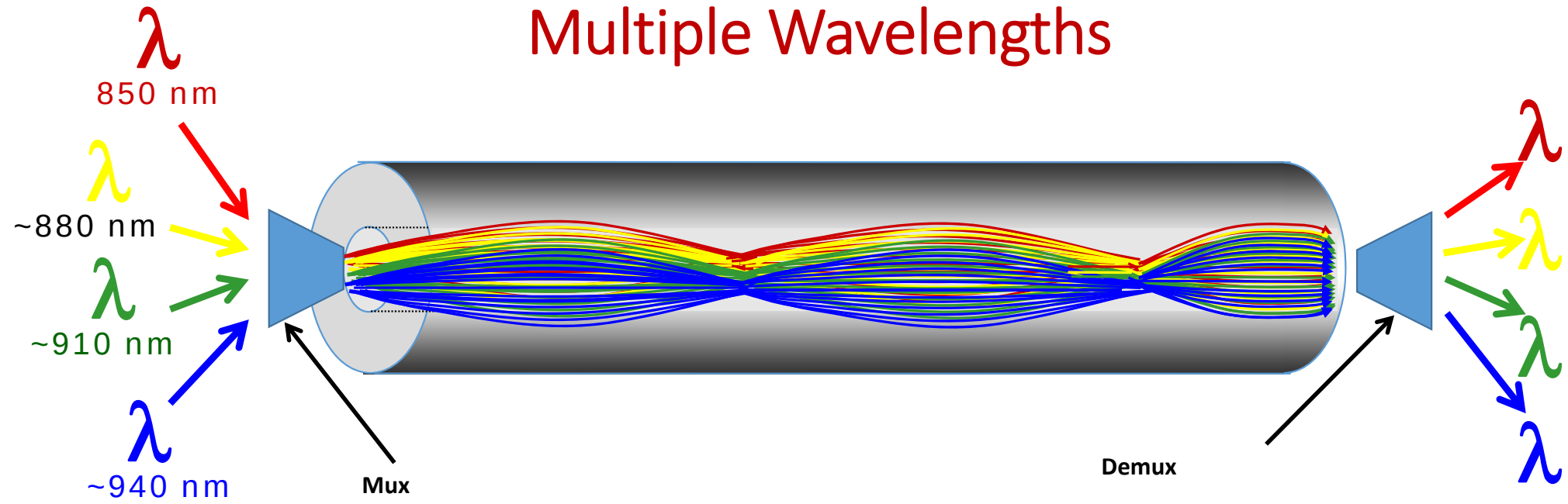
Multimode Fiber Designation	Multimode Fiber Type	Description	Recommended Application Range
OM1	62.5 um	"FDDI"-Grade	1 Gb/s
OM2	50 um	Dual Window	1 - 10 Gb/s
OM3	50 um	Laser Optimized	10 - 100 Gb/s
OM4	50 um	Laser Optimized *Extended Reach*	10 - 400 Gb/s
OM5	50 um	Wideband for SWDM	40 - 400+ Gb/s on fewer fibers

New Multimode Fiber Technology

Multimode traditionally operates at one wavelength



OM5 WideBand Multimode – Multiple Wavelengths



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

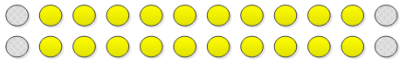
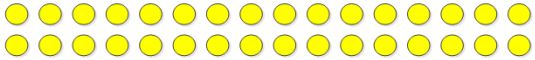
- Same as commonly used on Singlemode fiber:
  - **CWDM** (Course Wavelength Division Multiplexing)
  - **DWDM** (Dense Wavelength Division Multiplexing)

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

***Short* Wavelength Division Multiplexing**

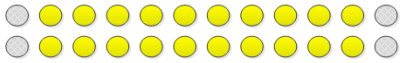
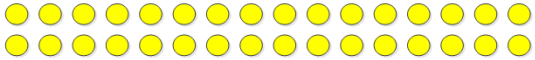
Parallel QSFP Multimode Fiber Migration Path

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 Multimode 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

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

Multimode vs. Singlemode 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

Conclusions

- ✓ Data Rates are increasing at ever faster rates *(10G → 40G → 100G → 200G → 400G)*
- ✓ OM1 and OM2 MM fibers are becoming obsolete.
  OM3 & OM4 are the current "work horse" MM fibers.
  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)*.

Fiber Market Trends

Darryl Heckle

Global Multimode Product Line Manager

Corning Incorporated

Bandwidth Drivers

It’s All About The Cloud

Companies	
Rackspace	YouTube
Salesforce	Facebook
Google	Amazon Web Services
Microsoft	Netflix

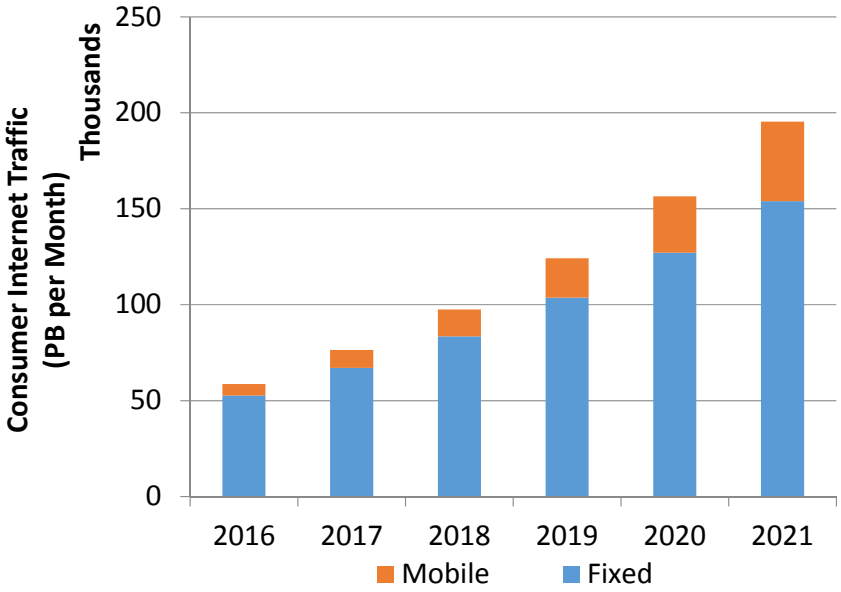
Global Network Traffic Growth Forecast

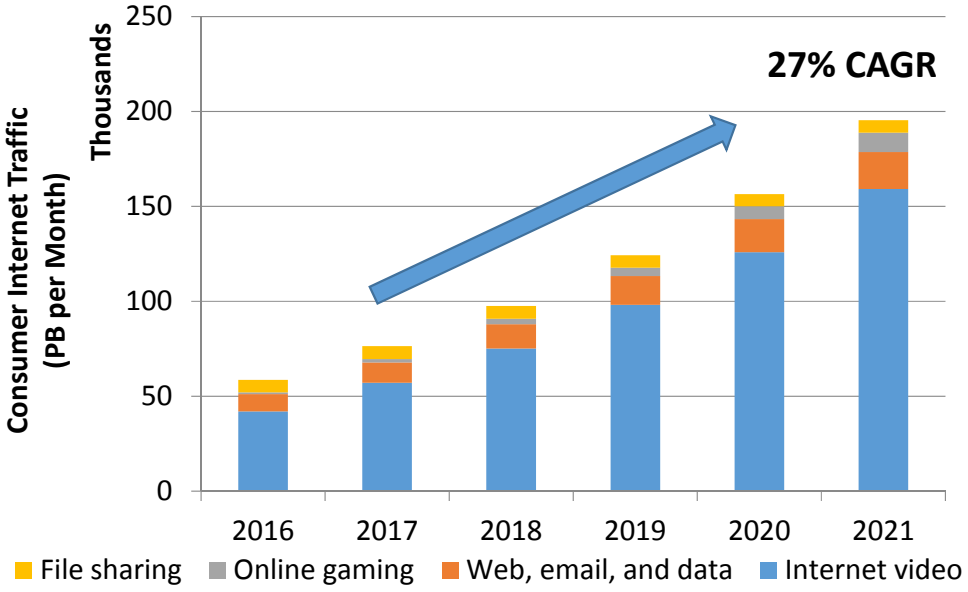
	2016	2021
Internet Users *(% of population)*	44%	58%
# Devices & Connections *(per capita)*	2.3	3.5
Avg. Speeds	27.5 Mbps	53.0 Mbps
Avg. Traffic *(per capita per month)*	12.9 Gb	35.5 Gb

Source: Cisco VNI, 2017

Global Consumer IP Traffic Growth

Video Applications Driving Growth



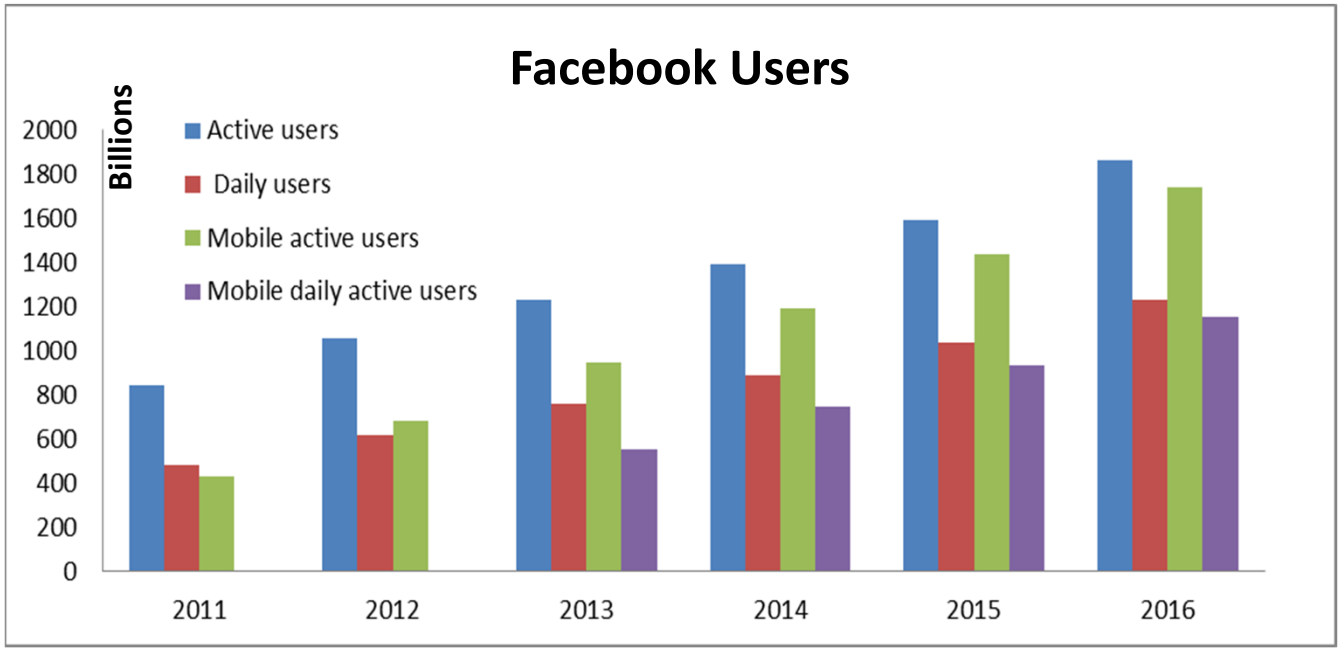


Source: Cisco VNI, 2017

Internet Applications

Mobile access driving growth

- **Facebook** (as of Sept 2017)
  - 2.07 billion active users, 1.37 billion daily users

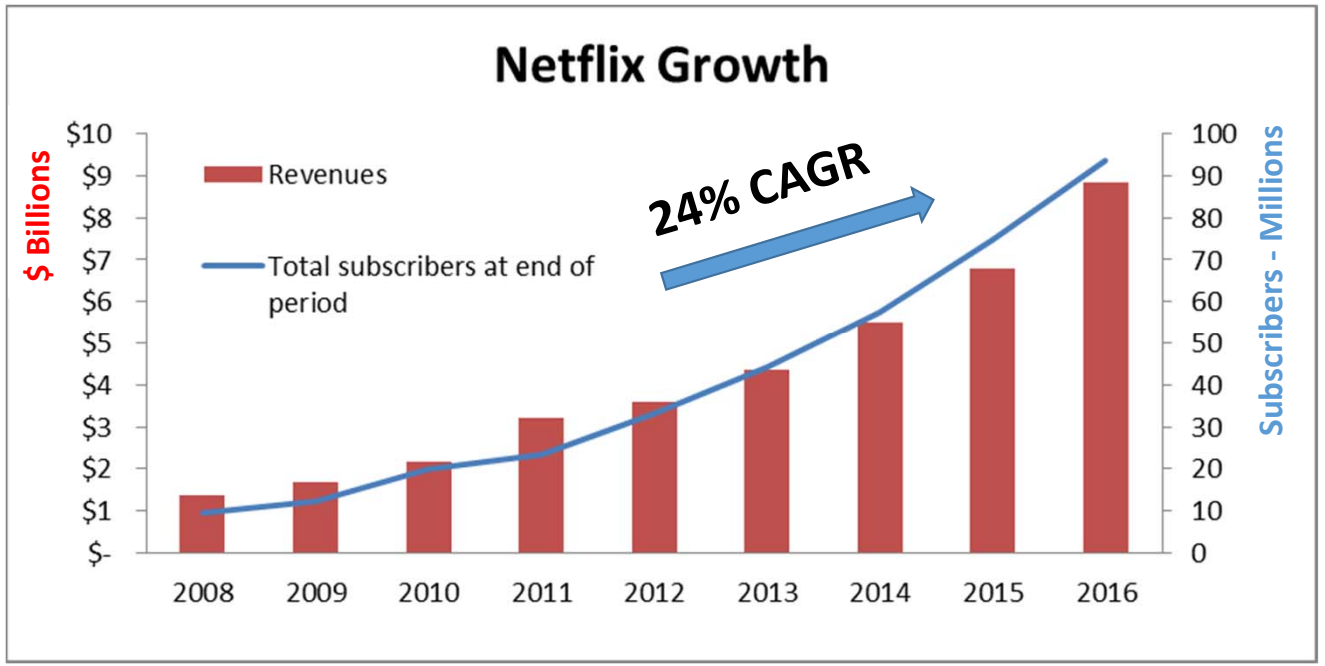


Source: http://newsroom.fb.com/Key-Facts

Internet Applications

Significant growth for on demand video

- **Netflix** (2017 Forecast)
  - 115.55 million members
  - $11.7 billion revenue

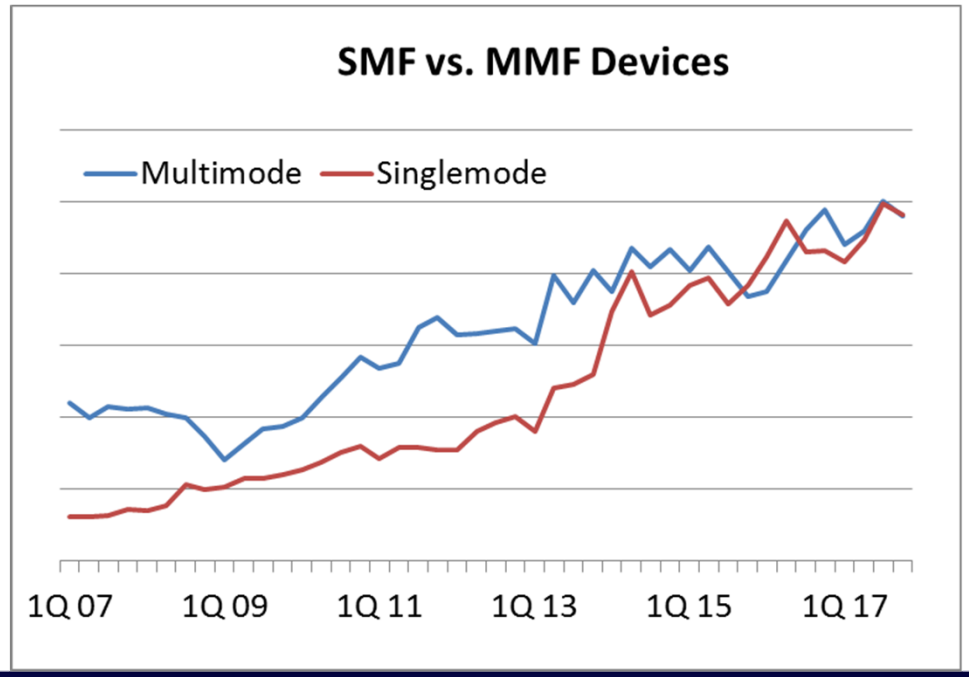


Source: http://ir.netflix.com/index.cfm

Ethernet Market

Ethernet Transceivers Sales

SMF and MMF device sales continues to grow

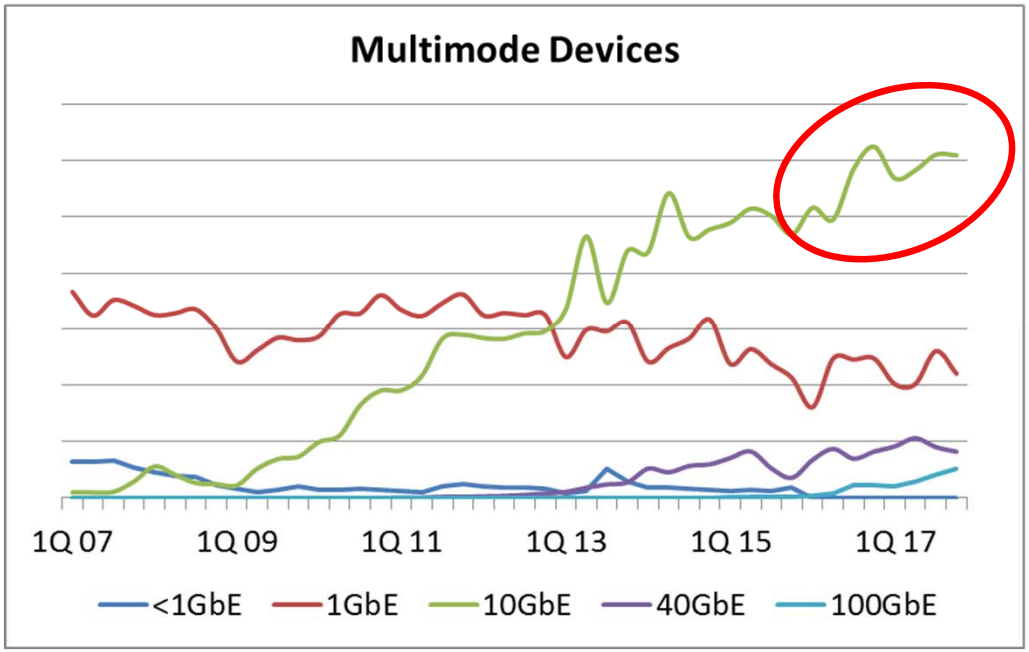


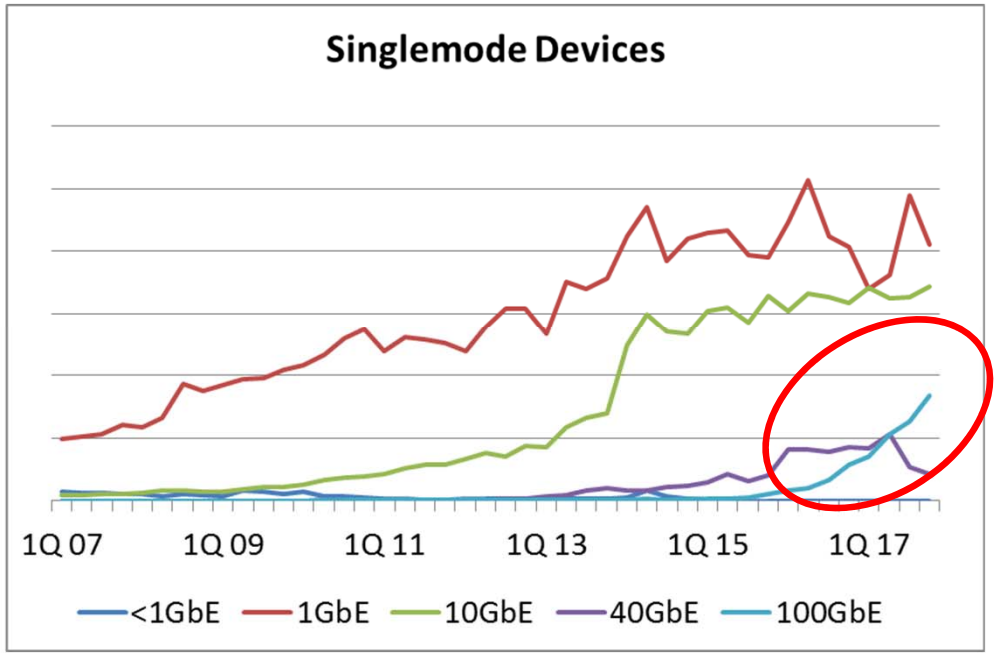
Source: Lightcounting Quarterly Market Report Dec. 2017

MMF and SMF transceiver speeds

Strong growth in 10G MMF; 100G SMF

Source: Lightcounting Quarterly Market Report Dec. 2017

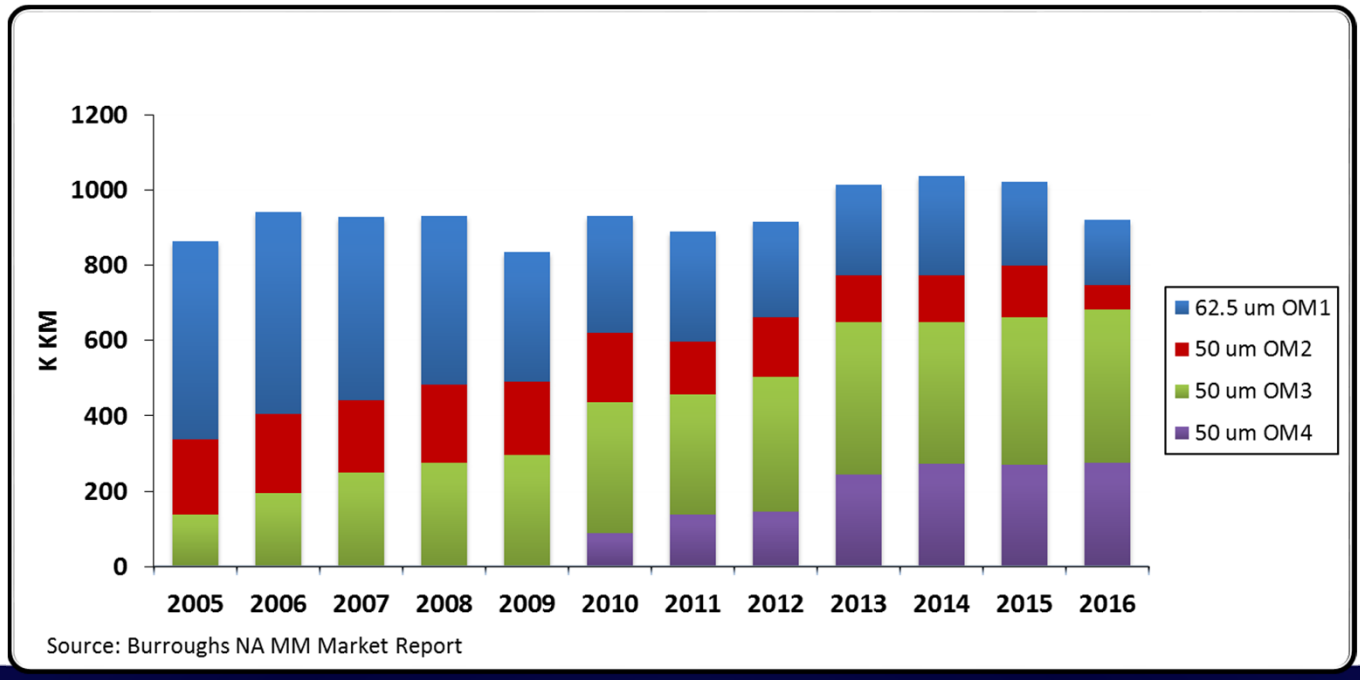




Fiber Market Trends

NA Multimode Fiber Volume by Type

OM3+4 volume growing; OM1+2 declining

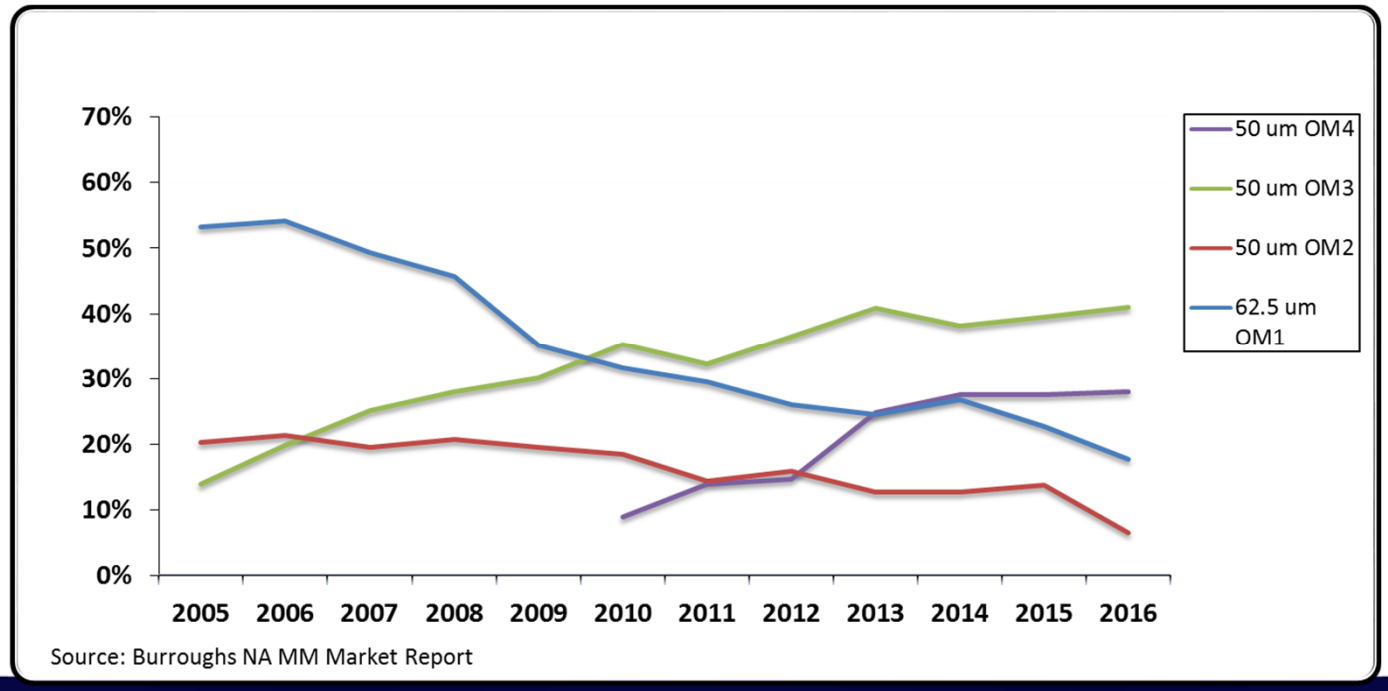


Source: Burroughs NA MM Market Report

Note: OM5 not reported separately.

NA Multimode Fiber Mix by Type

OM3+4 share growing at expense of OM1+2

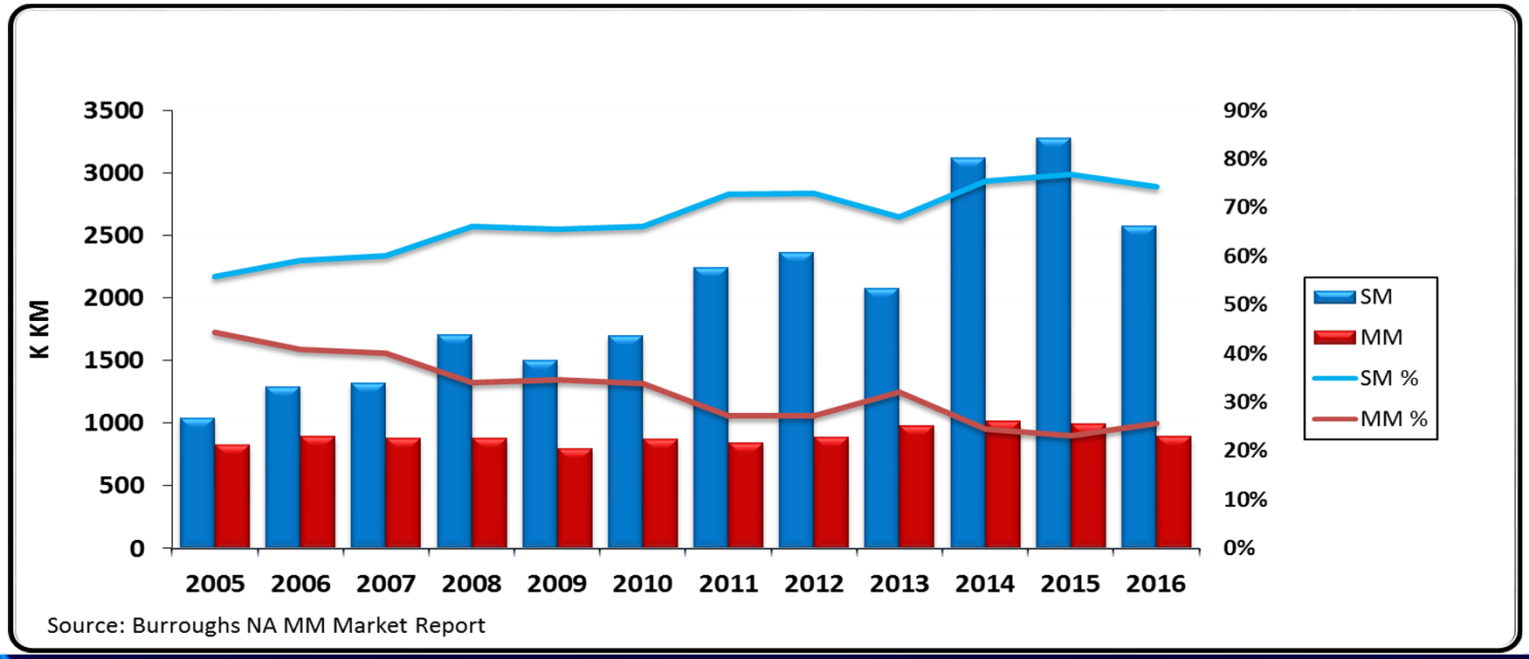


Source: Burroughs NA MM Market Report

Note: OM5 not reported separately.

MM vs. SM in the Enterprise

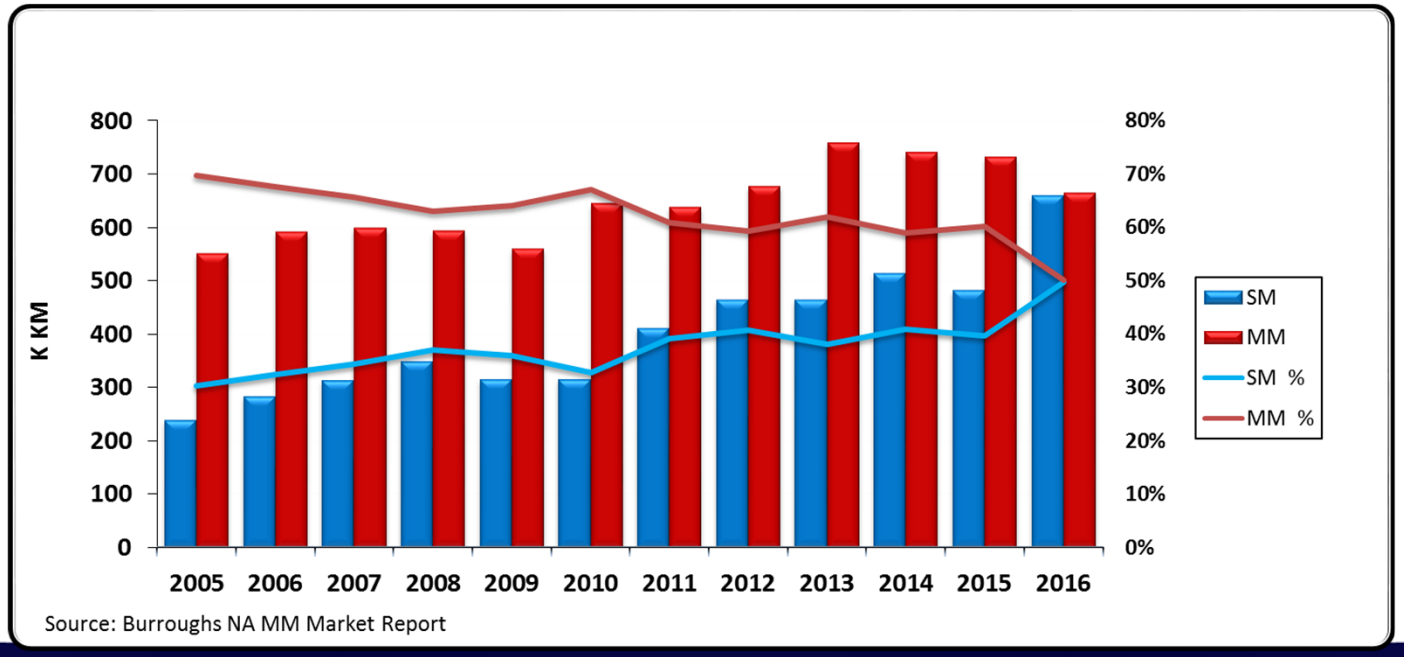
All Cable Types



Source: Burroughs NA MM Market Report

MM vs. SM in the Enterprise

Tight Buffer Cable



Source: Burroughs NA MM Market Report

Conclusions

- ✓ Bandwidth demands continue to increase
  - ✓ Mobile usage; video; social media
- ✓ Ethernet device demand continues to increase
  - ✓ Strong growth in MMF 10G networks
  - ✓ SMF devices growing, fastest at 100G
- ✓ OM4 demand continues to increase

Standard and Non-standard Transceivers Update

Robert Reid, Sr. Technical Manager

Panduit Inc.

Current Transceiver Form Factors (>=10G)

			
SFP	SFP+	XFP	SFF
			
XENPAK	X2	GBIC	CXP
			
QSFP/QSFP+	CFP	CFP2	CFP4

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 SWDM transmission onto single fibers reducing fiber count (duplex-LC interface) for 40GbE, 32GFC and above
- Emergence of Cost Effective SM Optics: Driven by large volumes consumed by H-Scale entities

10G Transceiver History

High Cost → Low Cost

Low Risk Designs
Low Volume

High Volume
Tooling Intensive

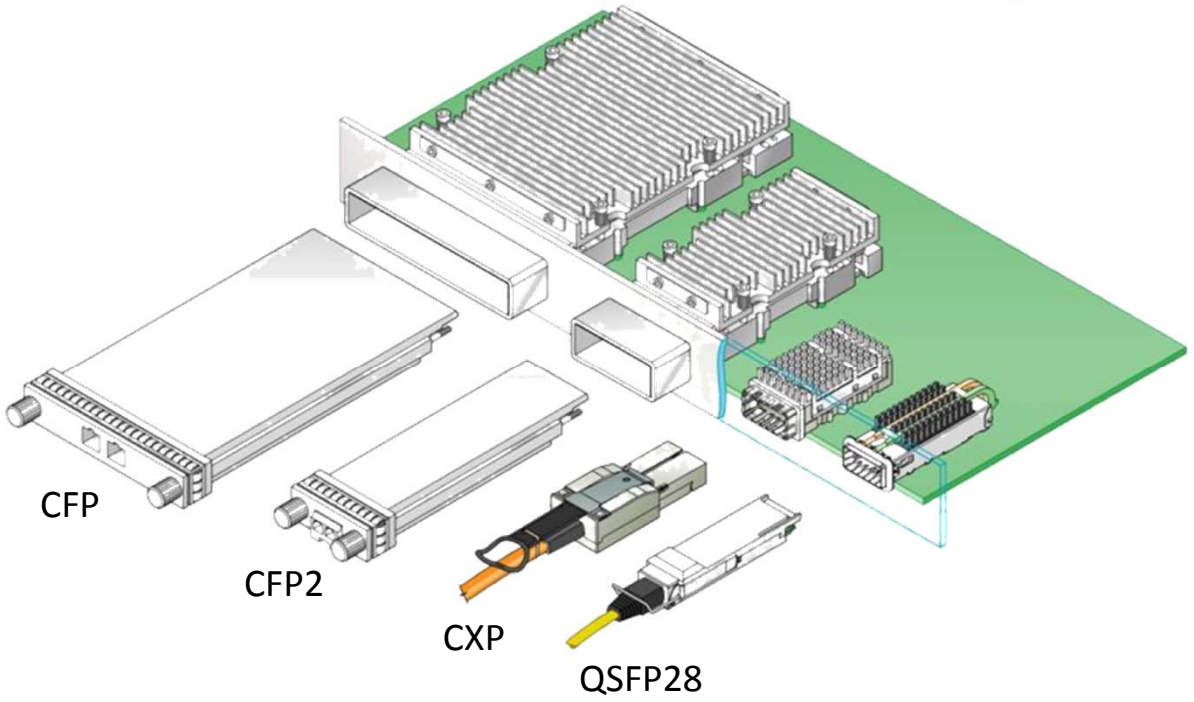
Item	300 Pin	XENPAK	X2	XFP	SFP+
Size (sq. in.)	10	6.75	5	2.2	1.2
Power (Watts)	10	8	4	2.5	1
Density	4	8	16	16/32	48

>10G Transceiver Roadmap

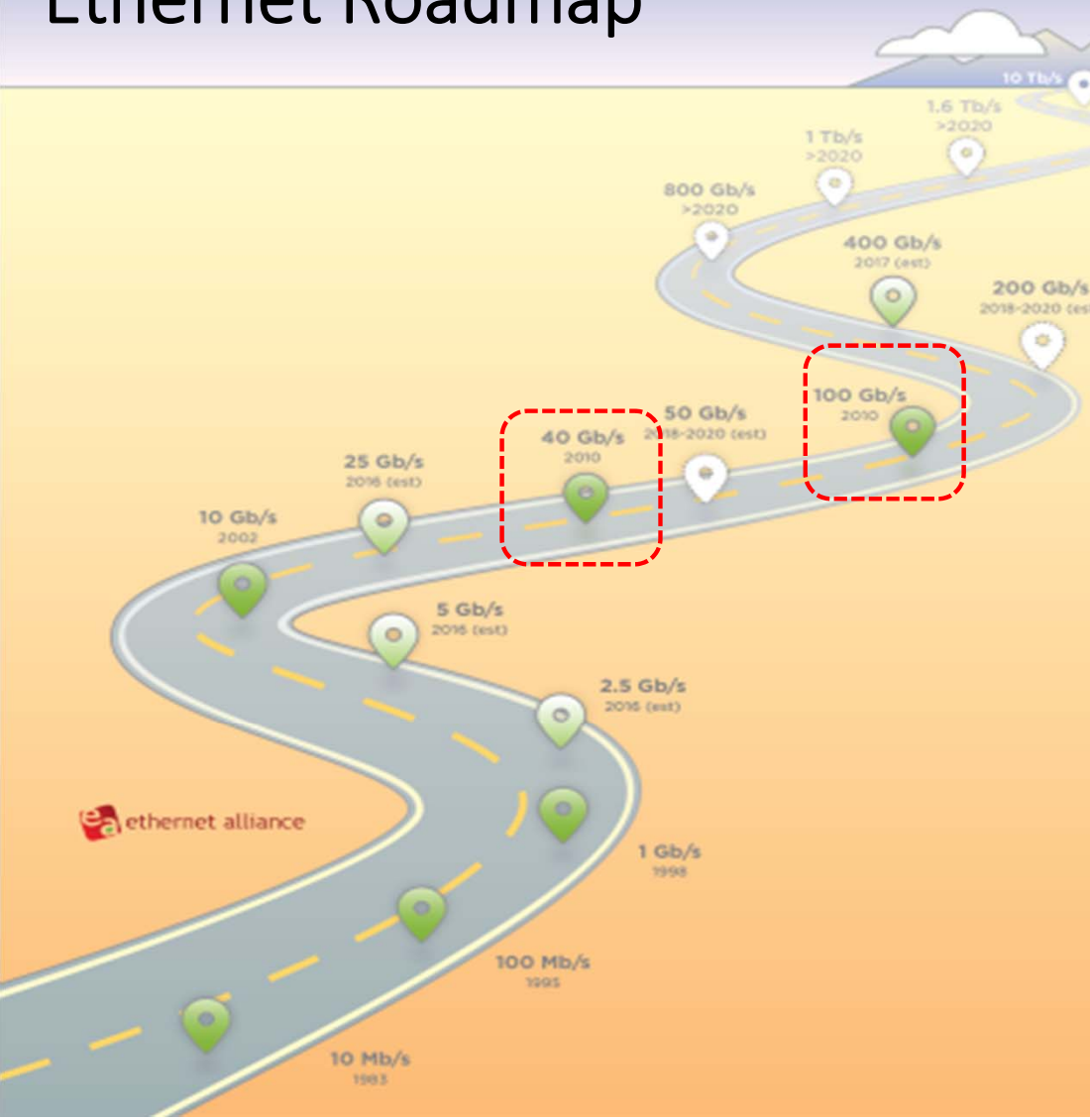
High Cost → Low Cost

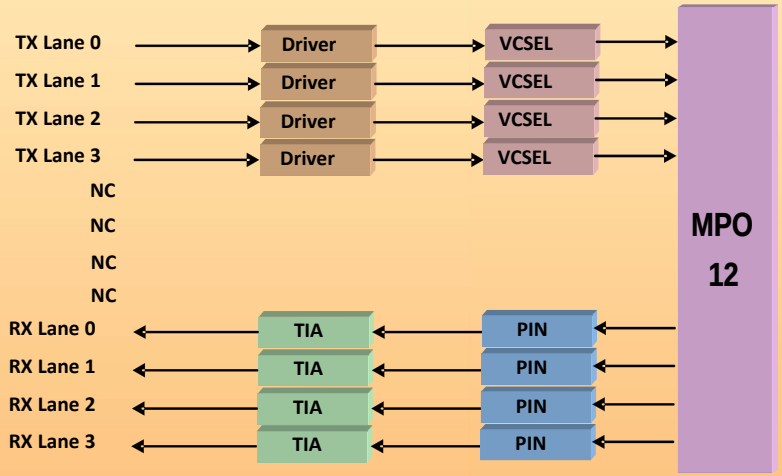
Low Risk Designs
Low Volume

High Volume
Tooling Intensive



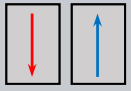
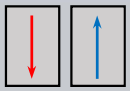
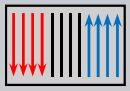
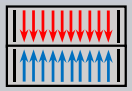
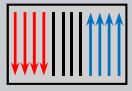
Ethernet Roadmap





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

Media Device Interface (10G to 100G)

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

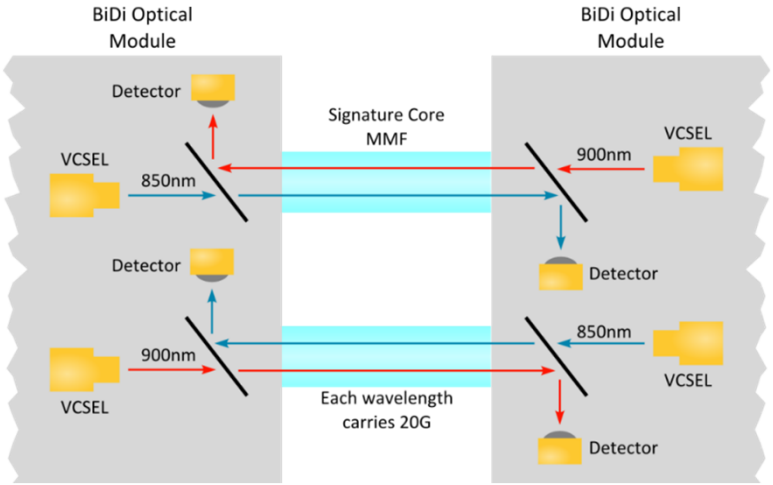
**IEEE P802.3bm approved May 10, 2015

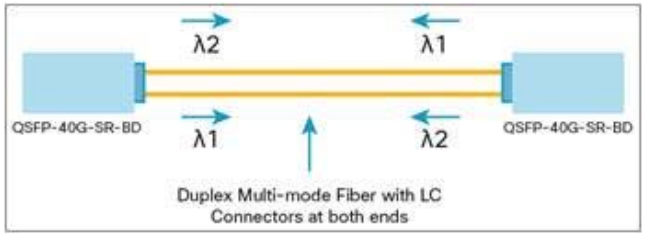
40GBASE-eSR4 'Extended'

- "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





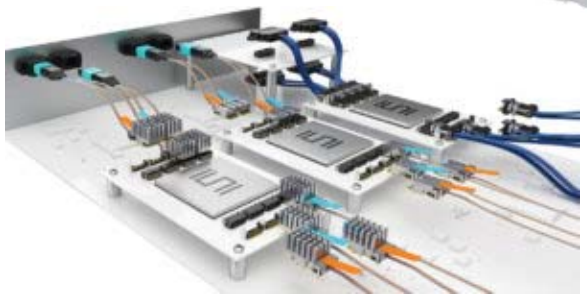
‘Universal’ Transceivers

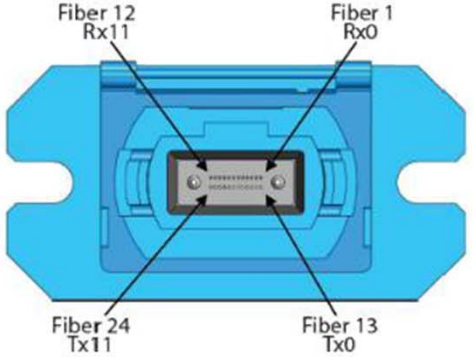
- Addresses customer concerns around the reduced distances with 40GBASE-SR4
- Migrations from existing 10 to 40GbE networking without requiring redesign/expansion of fiber network
- Supports operation over 150 m of OM3 or OM4
- Can be used for up to 500 m and with both 40GBASE-LR4 and 40GBASE-LRL4

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





cobo

Fibre Channel Higher Speed Optics

- 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)
  - Combine both 64GFC/256GFC (breakout?)
  - Modulation format (PAM-4) and 2/4 wavelength solutions
  - WideBand MMF is being introduced as a solution and cable plant models based on TIA/IEC standards being modeled

Brocade FC Optics

64G QSFP

2km SM version for ICL & 16G MM reach version for switch port app's

Fiber Channel Roadmap

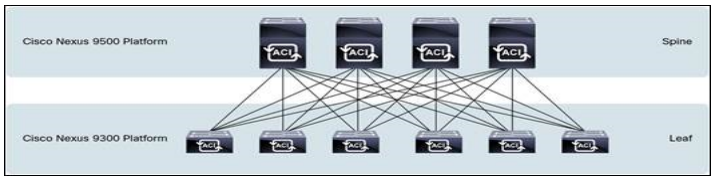
Product Naming	Throughput (Mbytes/s)	Line Rate (Gbaud)	T11 Specification Technically Complete (Year)*	Market Availability (Year)*
1GFC	200	1.0625	1996	1997
2GFC	400	2.125	2000	2001
4GFC	800	4.25	2003	2005
8GFC	1,600	8.5	2006	2008
16GFC	3,200	14.025	2009	2011
32GFC	6,400	28.05	2013	2016
128GFC	25,600	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

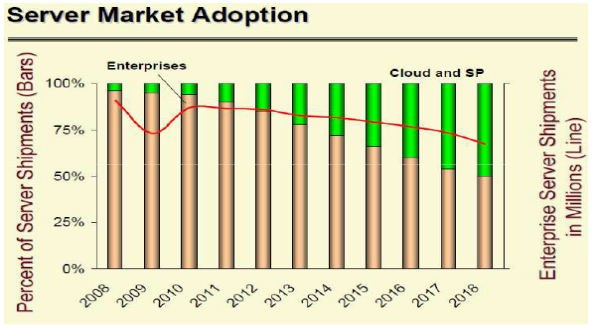
GEN 6 Fibre Channel

GEN 7 Fibre Channel

New Fiber Challenges

- Newer network designs (e.g., Flat Networks) require more transmission media to enable scalable and higher density solutions
- Large Enterprise/Webscale DCs are challenged to deal with significant transitions in the market to higher speed and longer reach channels
- Seamless infrastructure migration plans are necessary as data center port speeds are increasing (10Gb to 40Gb to 100Gb)





Hyperscale Market Segmentation

Google Mayes County

SuperNAP Las Vegas

LangFang DC - China

Cloud/SP customers want REACH & cost effective 100G!!!!

100G SMF Standards Activity

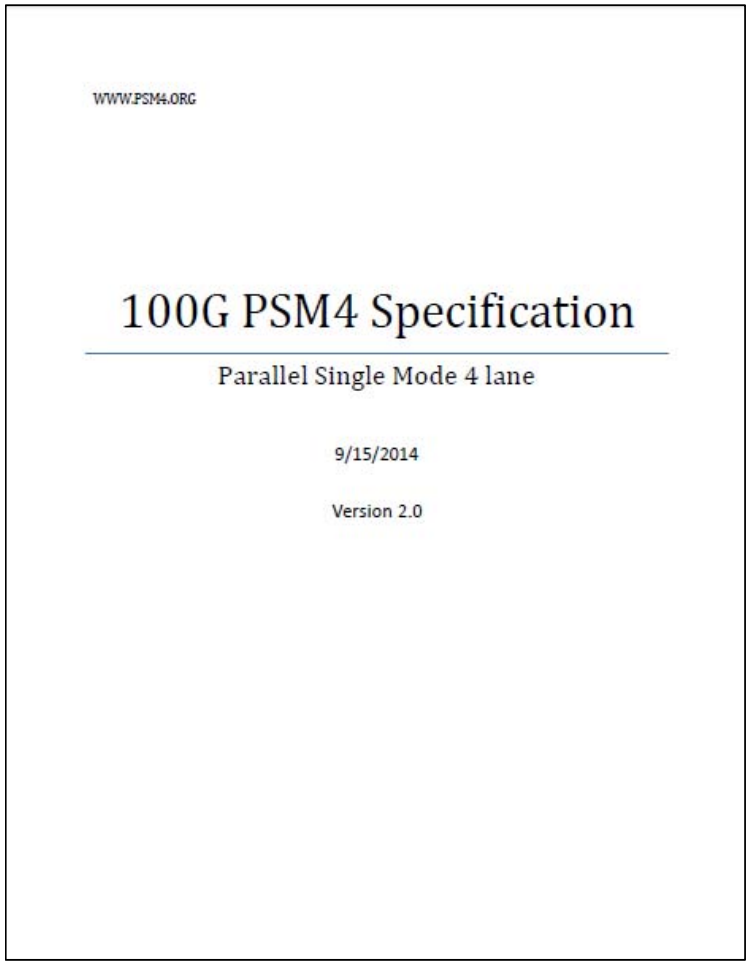
IEEE802.3bm task force named three contending technologies for SMF (link distance ≤2km) at its final closure in 2014.

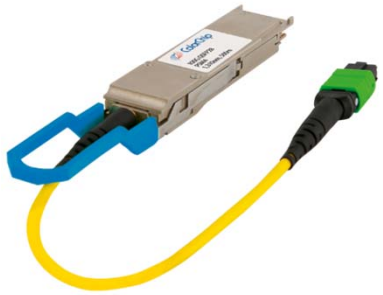
- CWDM (coarse wavelength-division-multiplexing),
- PSM4 (parallel single-mode fibers with 4 lanes in each direction)
- PAM-8/16 (pulse amplitude modulation with 8/16 levels)

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

Emergence of SM Solutions



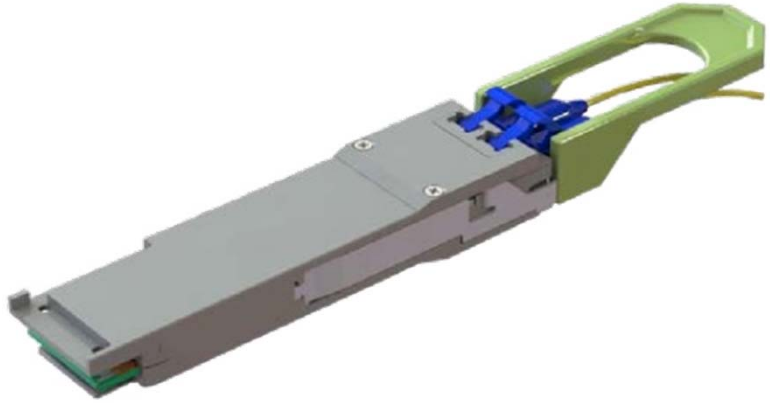


100G PSM4 MSA

- Industry Consortium - Low cost solution to extend reach within the DC for 100G interconnect
- Use of FEC to keep costs down (de-spec'd optics) 4 integrated modulators & one CW 1.3mm DFB laser
  - MPO connector with support for 8 active fibers
  - Reach <500 meters (<3.0dB of connector IL in cable plant)
  - Breakout possible (same cabling components as 128G FC)

CWDM4 & CWDM4-OCP

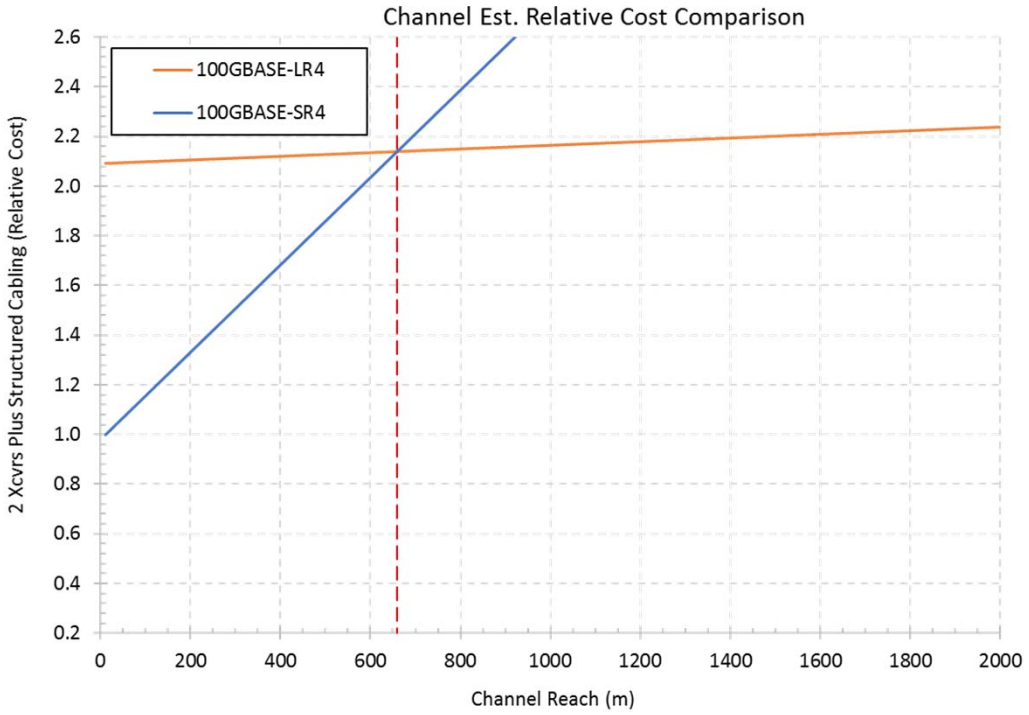
- 100G CWDM4-MSA
  - QSFP-28 form-factor
  - Single-mode duplex fiber
- CWDM4-OCP:
  - Relaxed specification for DCs
  - Reduced temperature range
  - Reduced link budget



	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)

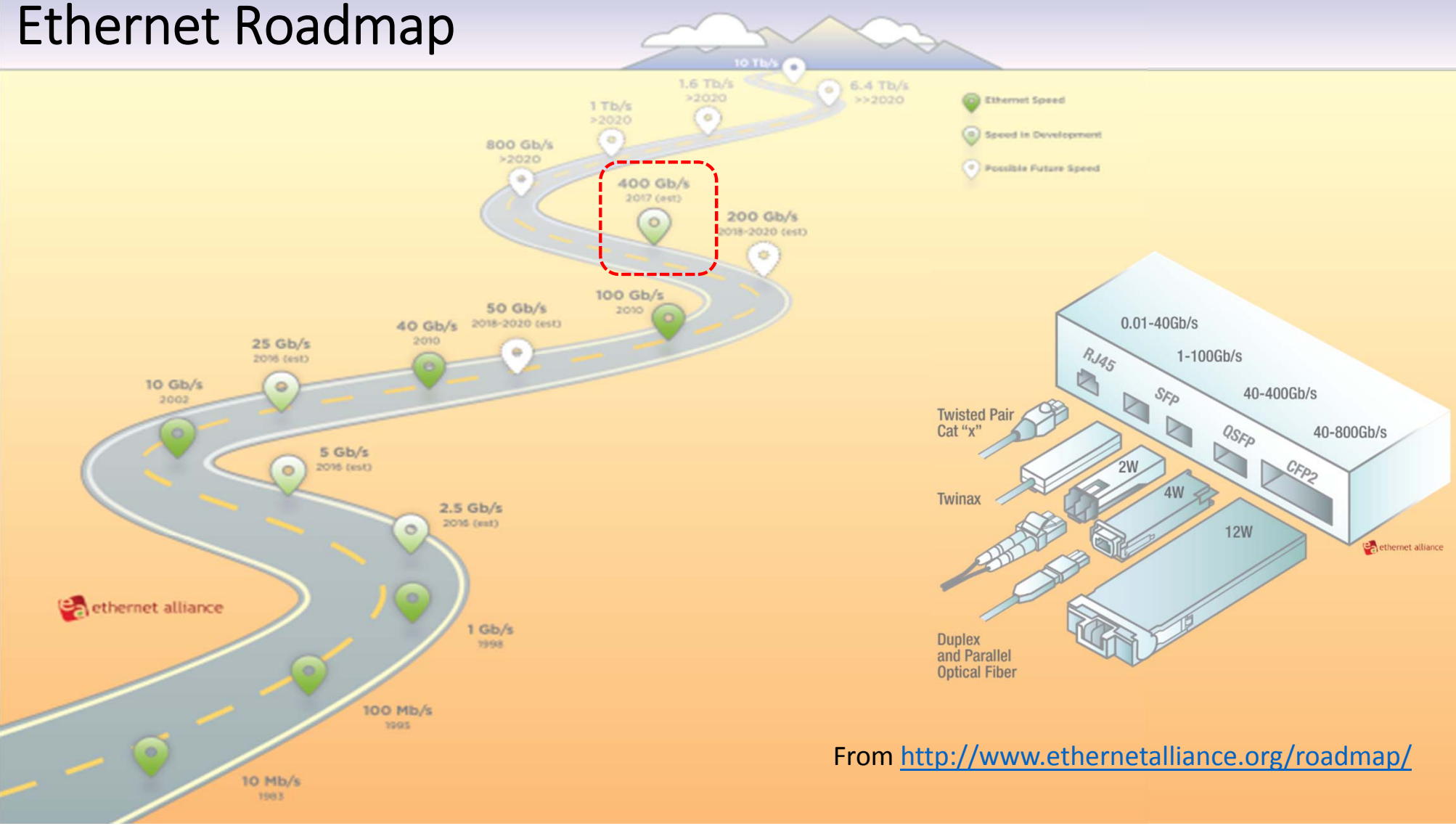
100G Xconnect Channel Compare



4 Cassette Link Scenario

Data presented will differ according due to unique installation and application requirements

Ethernet Roadmap



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

400G Candidate Technology

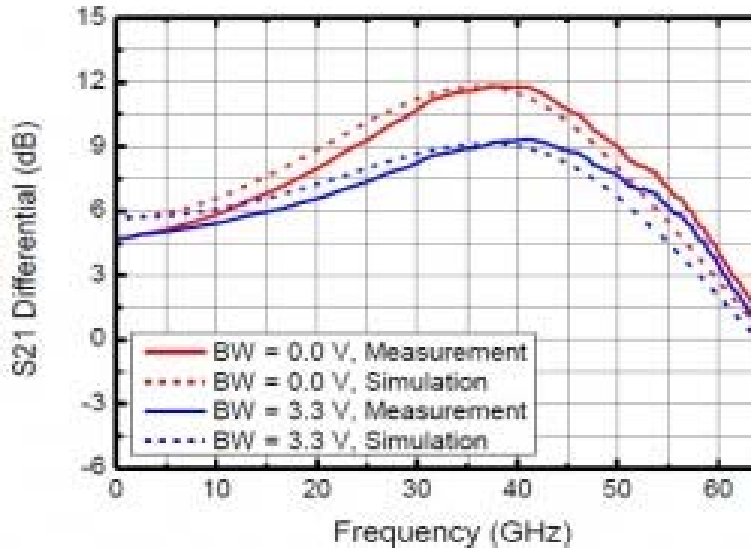
- Serial - Signaling rate of VCSEL transmitter (40GHz to 60GHz has been demonstrated)
- Parallel - Multiple lane aggregation (SR4, SR10, SR16)
- WDM - Wide Band MMF designed to take advantage of this (new fiber designed to enable 4+ wavelengths)
- Encoding - Conventional is NRZ (two symbols – symbol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

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.

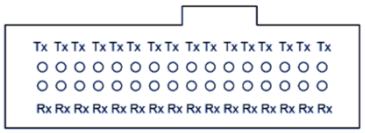
BERLIN, Germany, Apr 11, 2016

Customer samples of the VCSEL driver and TIA chip are available now June 27, 2017



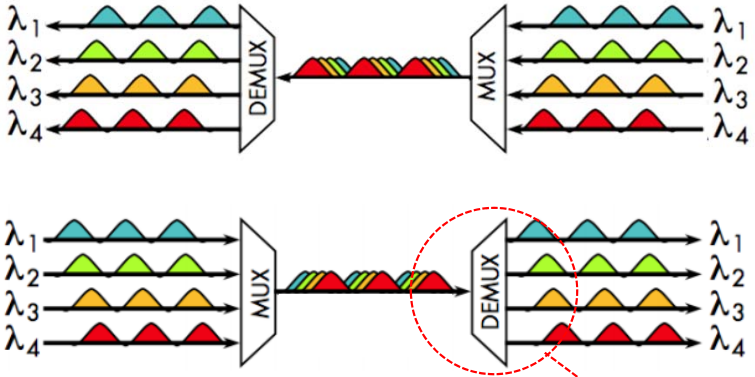
“Brute Force” - Multiple Lanes

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



32F/16F MPO?

SWDM Module Technology



- Multiple VCSELs at different wavelengths around 850 nm
- Passive optical multiplexing of light occurs within the module
- On Rx side, demultiplexing (using the same type of passive optic)

SWDM Module Technology

"Multi-Source Agreement" (MSA) defining use of the 840nm to 953nm wavelengths for the WDM transmission over WBMMF & non-WBMMF……40G/100G SWDM4 released.

Pros:

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

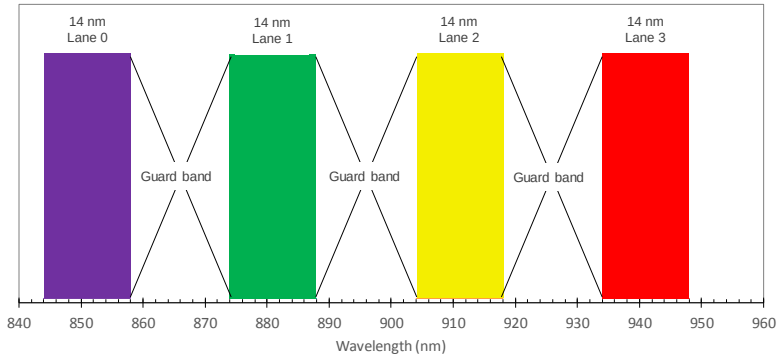
Cons:

- SWDM ecosystem - transceivers/fiber expensive
- Transceiver complexity, power consumption
- SWDM doesn't support breakout

SWDM Wavelengths (2λ vs. 4λ)

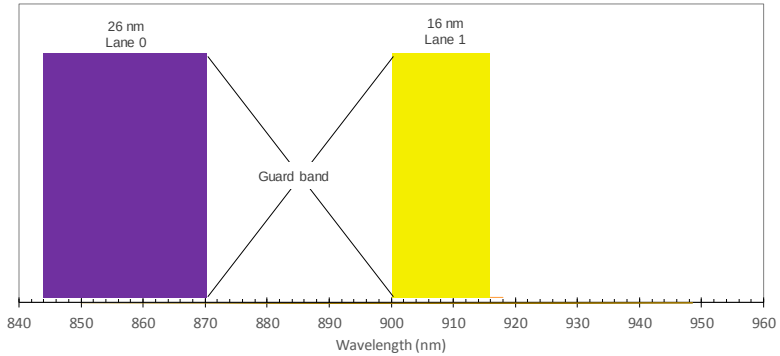
4λ SWDM

- Tighter specs
- Higher WDM insertion loss
- Increased cross-talk penalty
- Higher power VCSELs required
- Higher power dissipation



2λ SWDM Proposed in P802.3cd

- Larger guard band
- Wider spectral windows
- Lower WDM IL



PAM-4 Multilevel Encoding

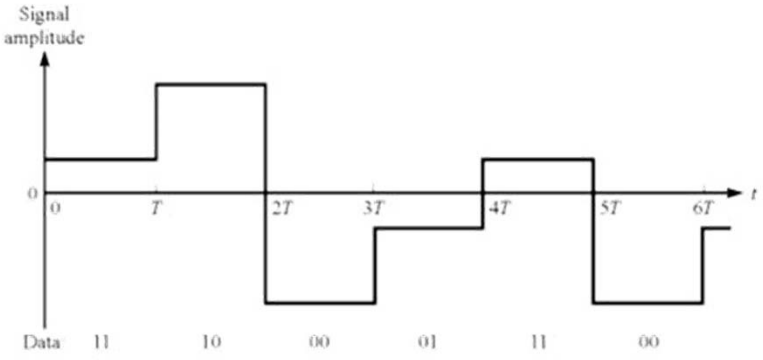
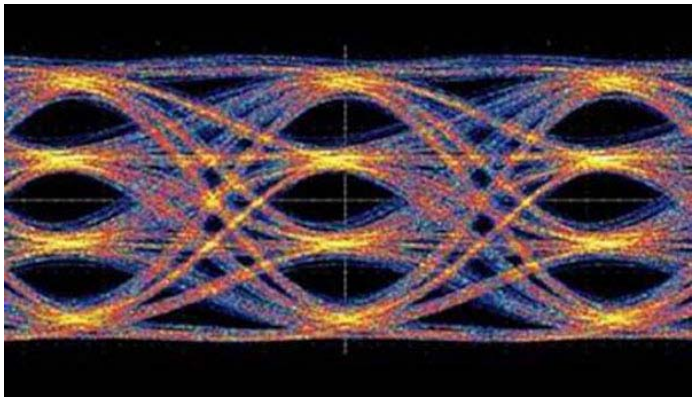


Fig.1 A PAM-4 signal in time domain. T= symbol period.



- 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

Options for Next Gen MMF PMDs

Technology (per fiber)	1 fiber pair	2 fiber pairs	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	400G-SR8	
2x50G-λ PAM4	100G-SR1.2	200G-SR2.2	400G-SR4.2		
4x25G-λ NRZ	100G-SR1.4	200G-SR2.4	400G-SR4.4		
4x50G-λ PAM4	200G-SR1.4	400G-SR2.4	800G-SR4.4		

Technology options for 200 & 400 Gb/s links over fewer MMF fiber pairs

Existing IEEE Standards

In Progress

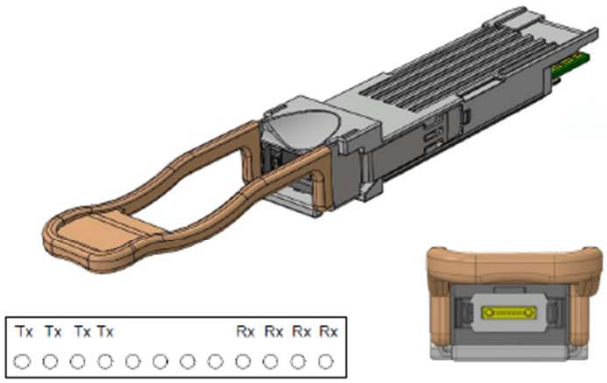
SRm.n

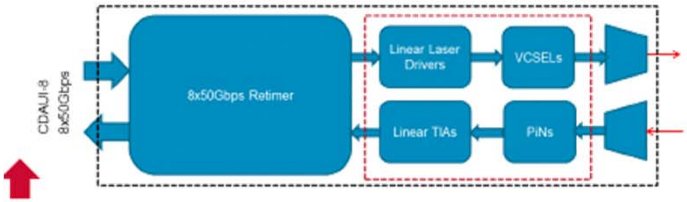
m = # of Fiber Pairs

n = # of Wavelengths

400GBASE-SR4 Example

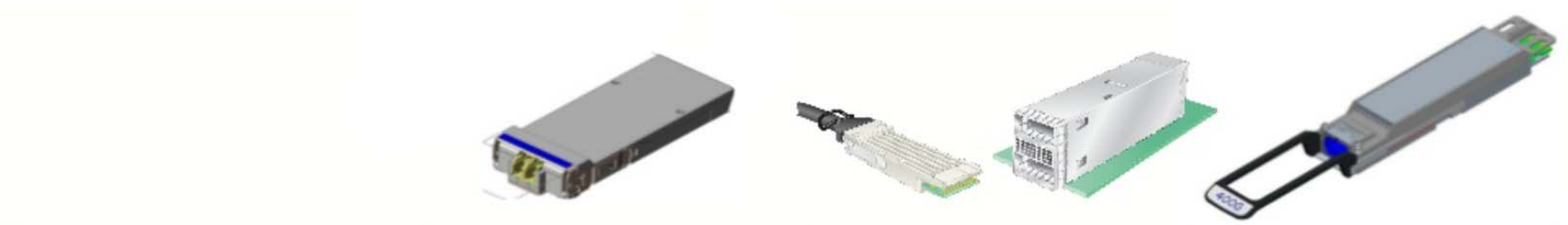
400G VCSEL100m SR4 OM4 MMF, (Two VCSEL λ, 4+4 MPO)
DD-QSFP (or OSFP) Form Factor





- 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

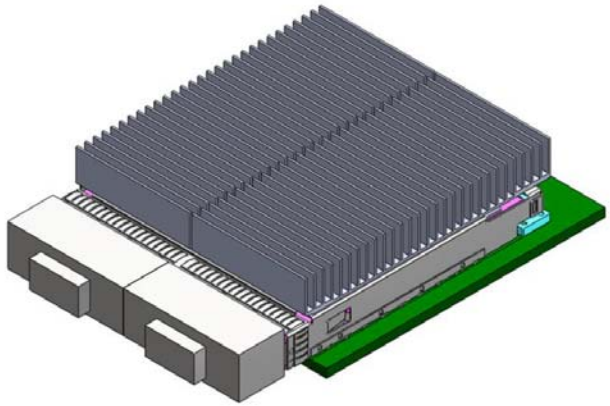
400G MSAs



	CFP8	QSFP-DD	OSFP
Size(HxLxT)	40x102x9.5	18.35x89.4x8.5	22.58x107.8x13.0
Terminal Capacity	12-18W	7-10W	12-15W
Organization	http://www.cfp-msa.org/	http://www.qsfp-dd.com/	http://osfpmsa.org/

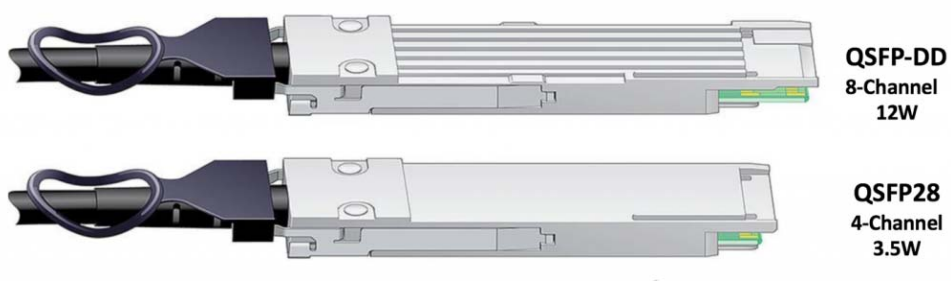
CFP8 - Targeted @ 400G

- 8 lane version of CFP MSA
- Supports up to 16 lanes vs. 4 of QSFP or QSFP28
- Each of the 16 lanes operates at 25G
- Max. 16 OSFPs per std. linecard slot
- Backward compatible to QSFP & QSFP28



QSFP DD - Targeted @ 400G

- Quad Small Form Factor Pluggable Double Density
- Supports 8 lanes vs. 4 of QSFP or QSFP28
- Each of the 8 lanes operates at 50G (4x rate of QSSP28)
- Max. 36 OSFPs per std. linecard slot
- Backward compatible to QSFP & QSFP28



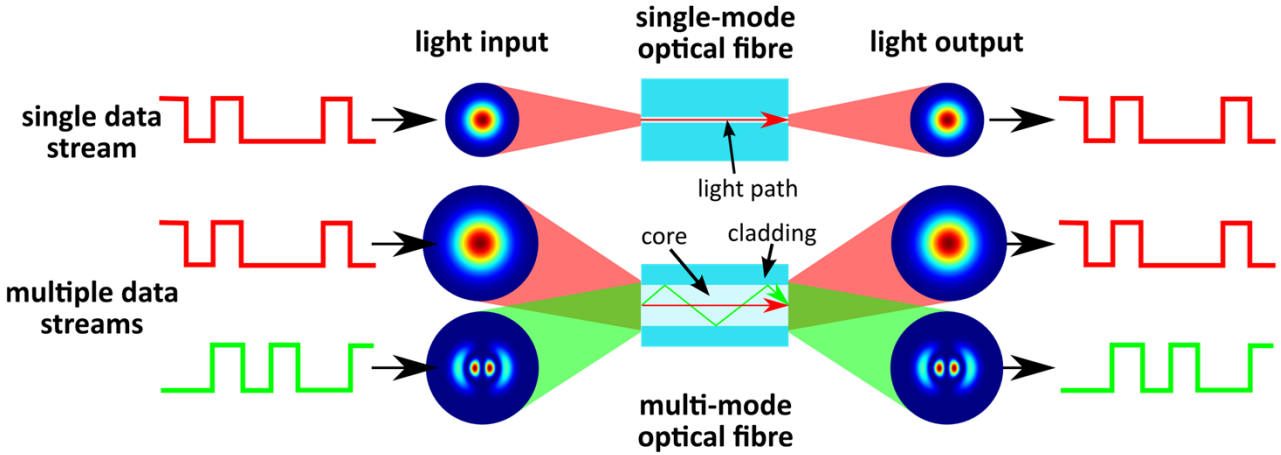
OSFP - Targeted @ 400G

- Octal Small Form Factor Pluggable
- Slightly Wider & Deeper than QSFP
- Not Backwards Compatible with QSFP or QSFP28
- Max. 32 OSFPs per std. linecard slot
- Roadmap to produce 800G (4x100G)

QSFP DD & OSFP - New MDI

Future Technology for MMF

Mode Division Multiplexing



- Has been used to extend the capability of 'legacy' MMF (62.5/125)
- May require the development of a new breed of MM fibers to optimize for many channels
  - "Few Moded Fibers"
  - (I call these 'Oligo'-mode fibers)

High Speed migration options

Rodney Casteel RCDD/NTS/OSP/DCDC

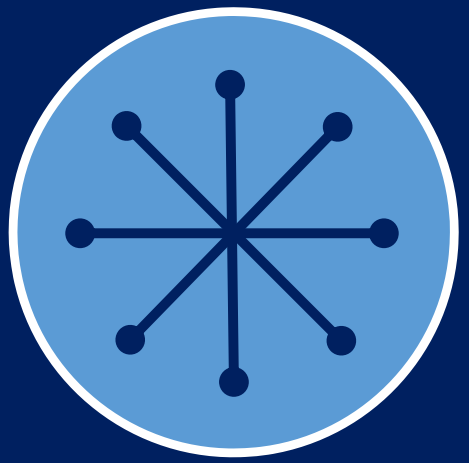
CommScope – Sr. Field Application Engineer

Chair – TIA Fiber Optic Technology Consortium

Data Centers undergoing change

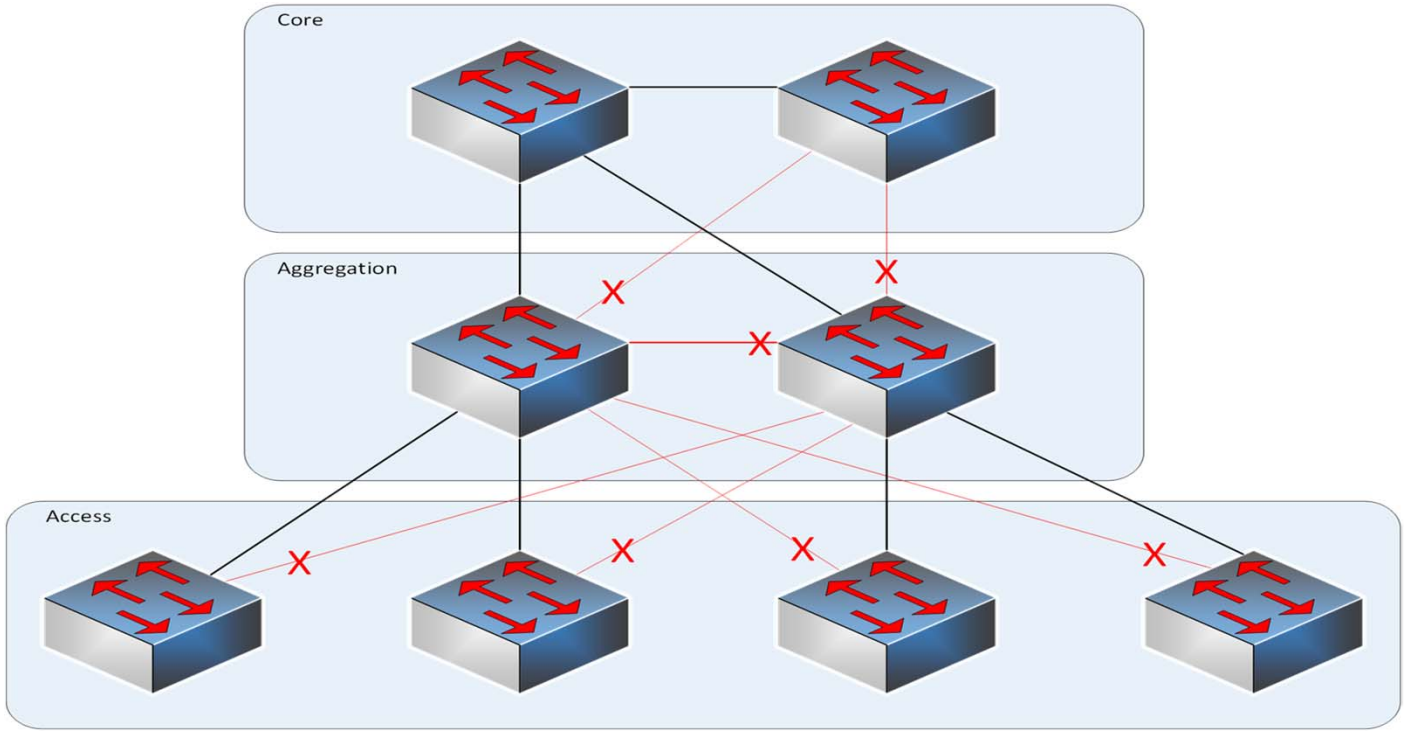
Bandwidth Explosion

Cloud Computing

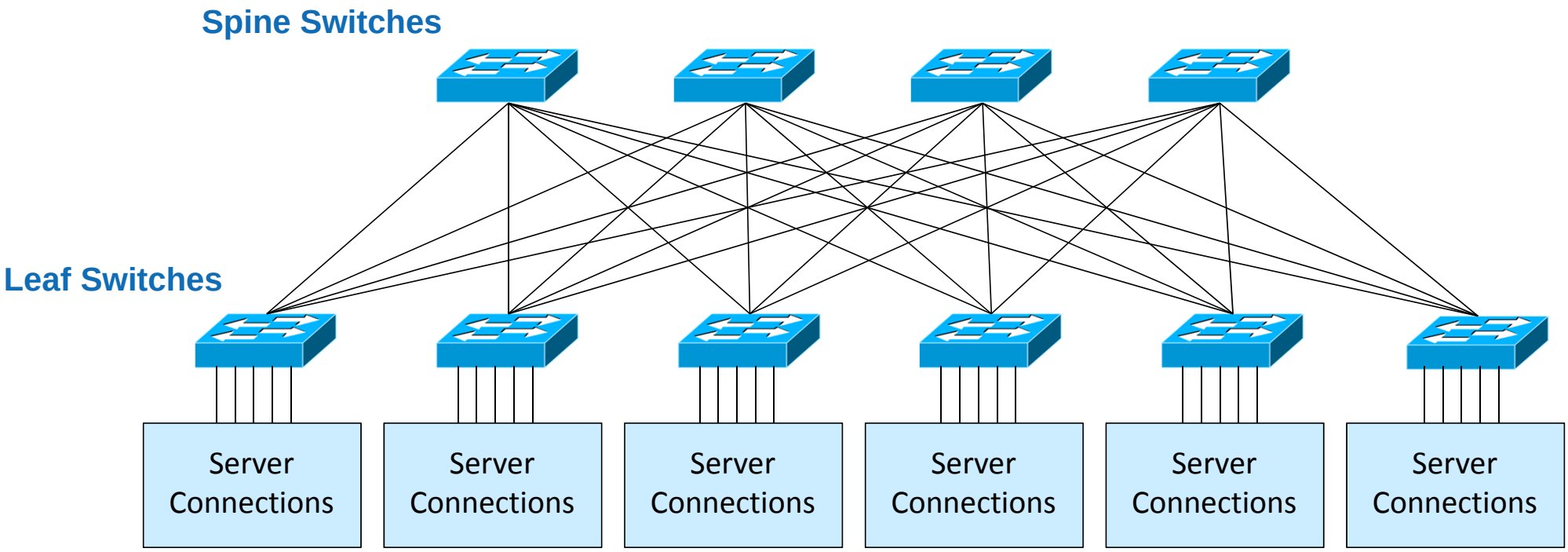


Internet of Things

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

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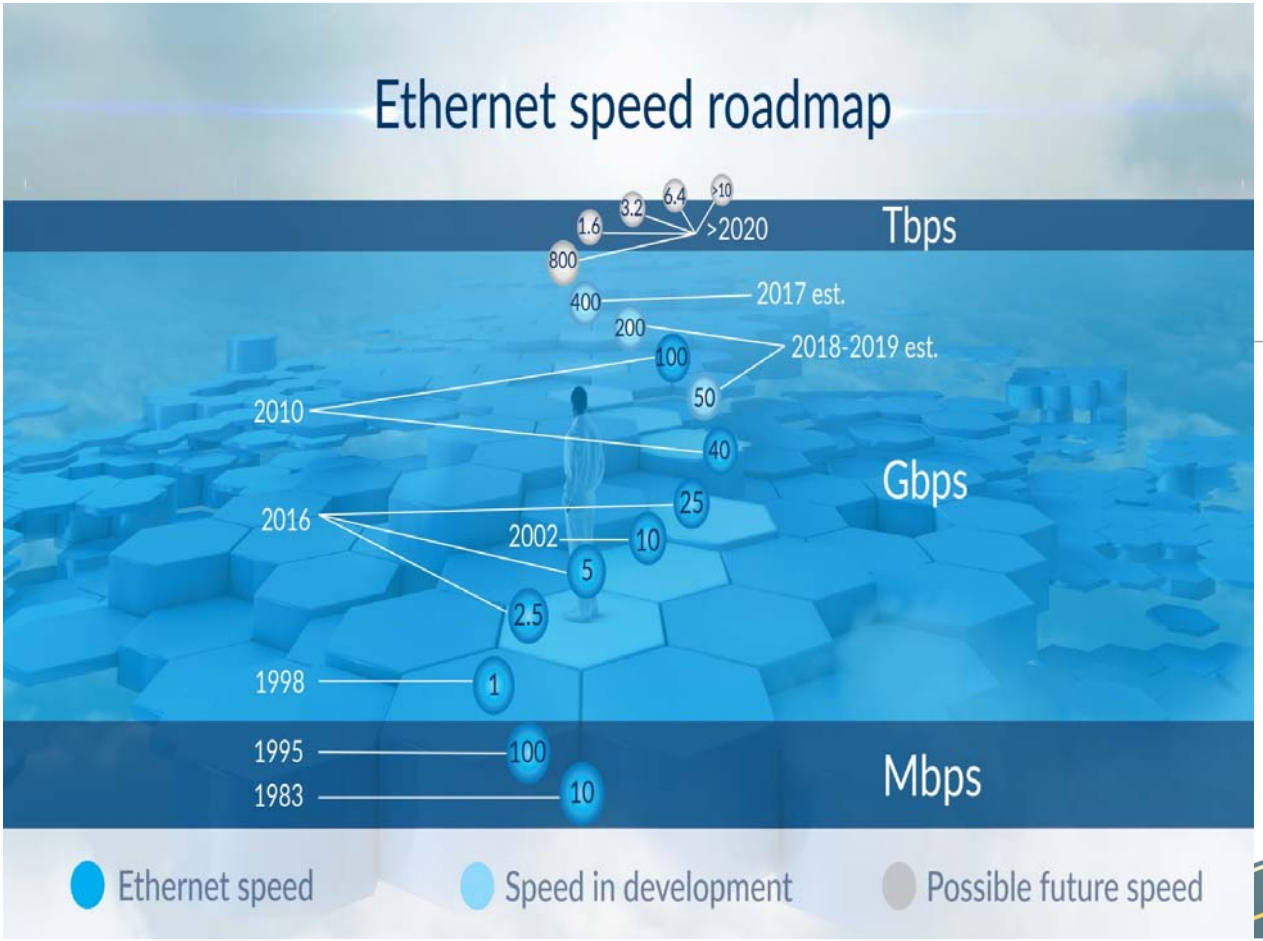
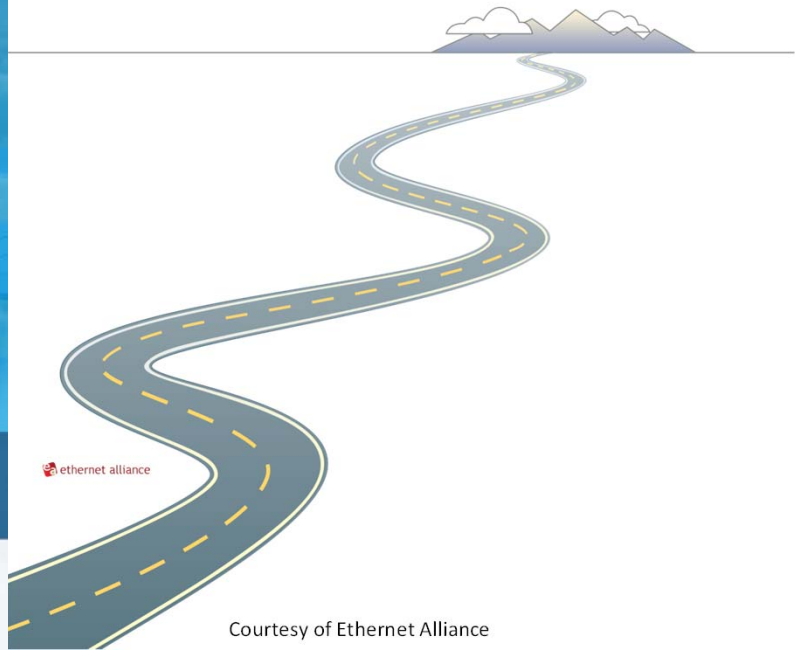
WHAT IS HIGH SPEED ?



How does your roadmap compare?



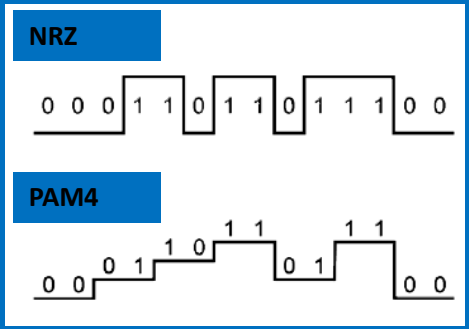
Courtesy of Ethernet Alliance

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

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

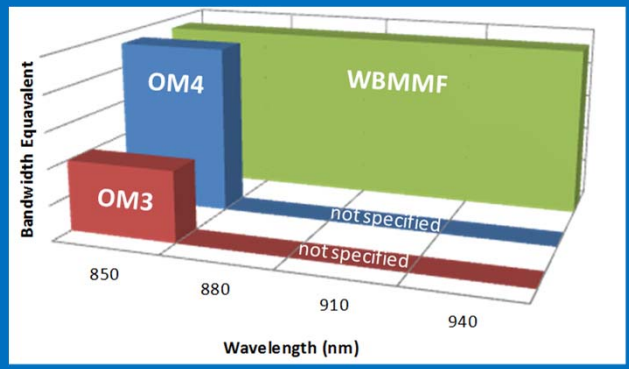


Enabling 50Gb per lane

SWDM
More Efficient Fiber Usage

Enabling 4 λ per fiber

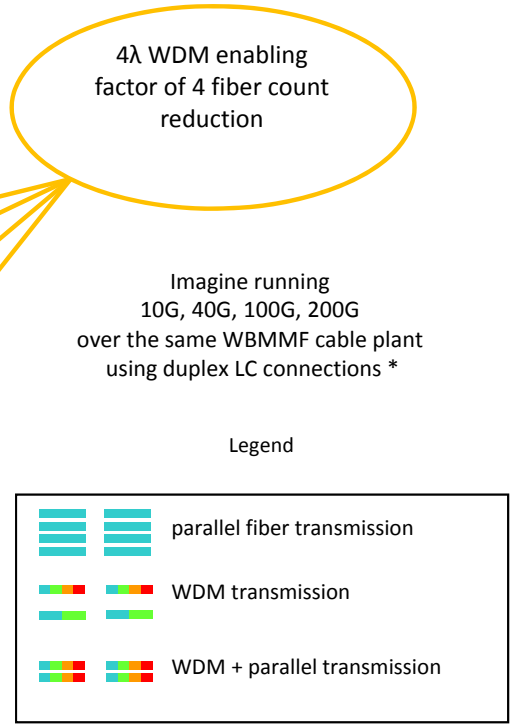
WBMMF
More Efficient Fiber



Supporting 4 λ per fiber to practical distances

Higher Speed Strategies

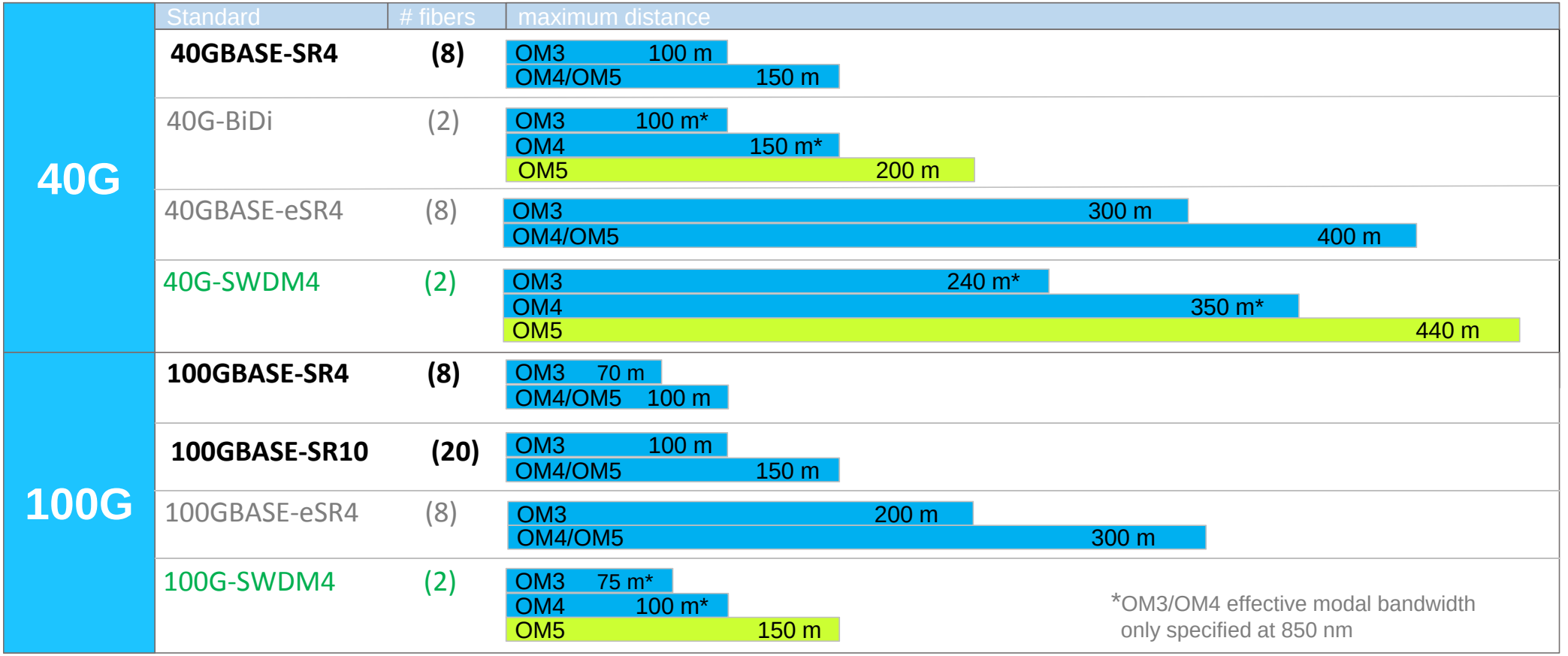
Data Rate	10G NRZ Parallel TX RX	25G NRZ Parallel TX RX	50G PAM4 Parallel TX RX	10, 25, 50G WDM & Parallel TX RX
40G		N/A	N/A	
100G				
200G				
400G				



*Parallel fibers remain essential to support break-out functionality

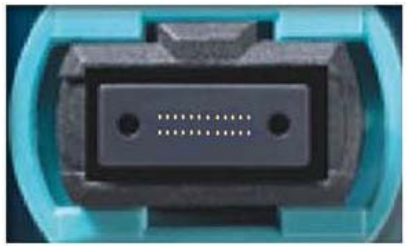
40G/100G Applications and Multimode Fiber

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



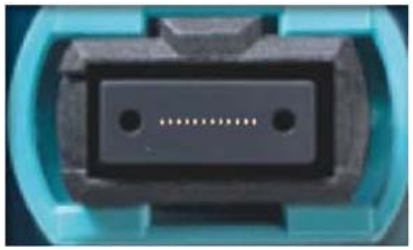
"In addition to supporting the same 850nm and 1300nm applications as OM4, *OM5 provides advantage in the support of future applications using WDM in the wavelength range 850nm to 953nm*" *(FDIS ISO/IEC 11801-1)*

MPO Options



24 FIBER

- HIGHER DENSITY
- FEWER COMPONENTS
- MORE COST EFFECTIVE



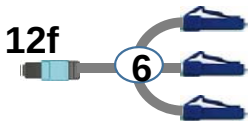
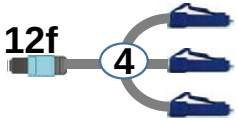
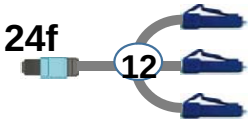
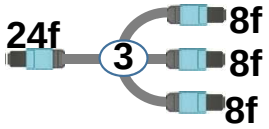
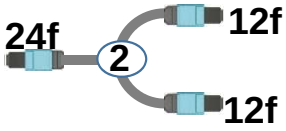
12 FIBER

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

8 FIBER

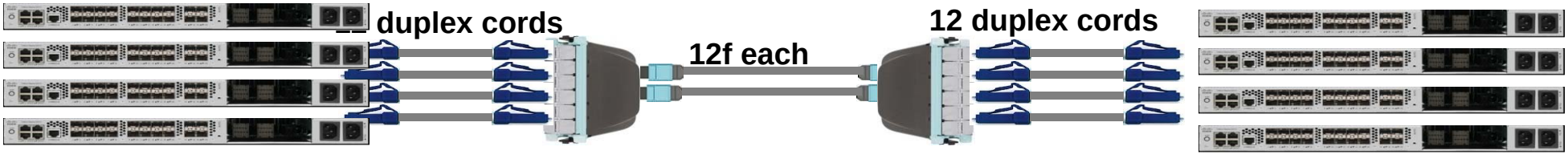
- SAME AS 12 EXCEPT ONLY USES 8 FIBERS
- NOT REALLY A STANDARDS RECOGNIZED INTERFACE
- USED MOSTLY FOR –SR4 APPLICATIONS

Array Connectivity = Application Support Flexibility

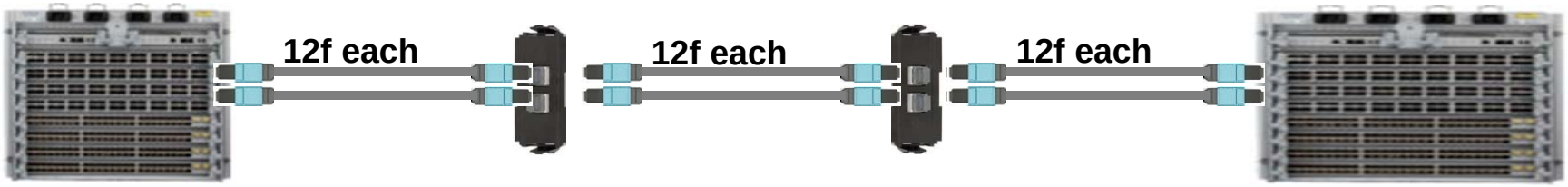
multiple 2-fiber applications on 12f cabling	MPO 12 active fibers		6 x duplex LC
40G-SR4 breakout to 10G-SR	MPO 8 active fibers		4 x duplex LC
120Gb/s breakout to 10G-SR	MPO 24 active fibers		12 x duplex LC
120Gb/s breakout to 40G-SR4	MPO 24 active fibers		3 x MPO 8 active fibers each
100G-SR10 on 12f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

Cabling Infrastructure Migration from 10G to 40G

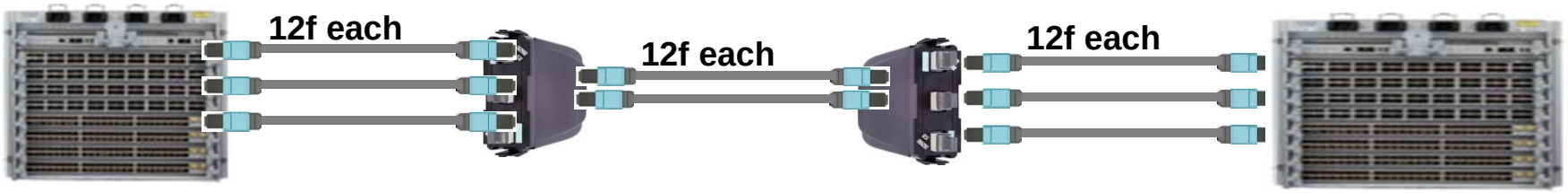
Existing 10G Connections using MPO trunk cabling



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

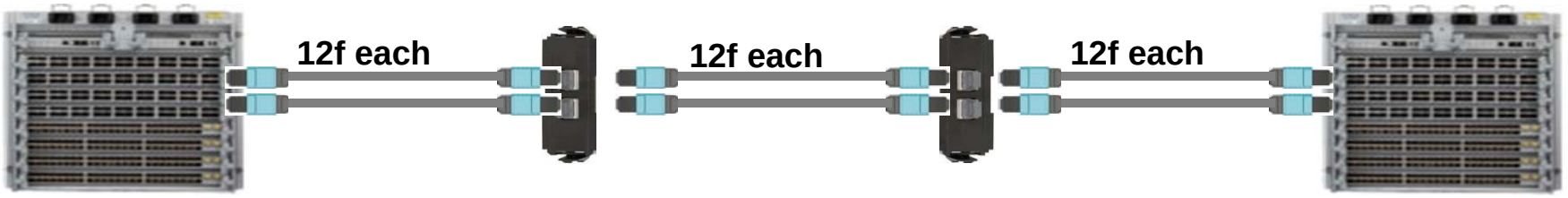


Migration to (3) 40G connections while retaining existing MPO cabling with 100% fiber utilization in trunk cables

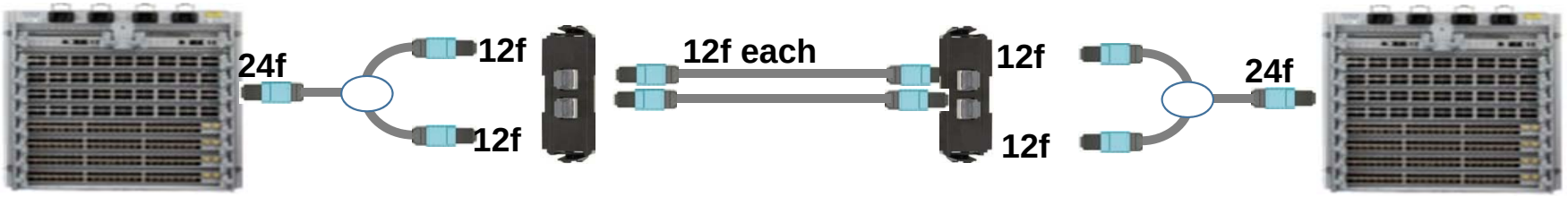


Cabling Infrastructure Migration from 10G to 40G

Existing (2) 40G connections using MPO cabling

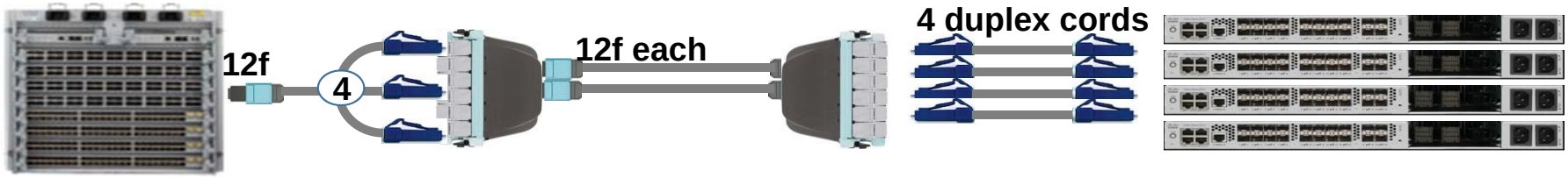


Migration to 100G connection while retaining existing MPO trunk cabling and adapter panels

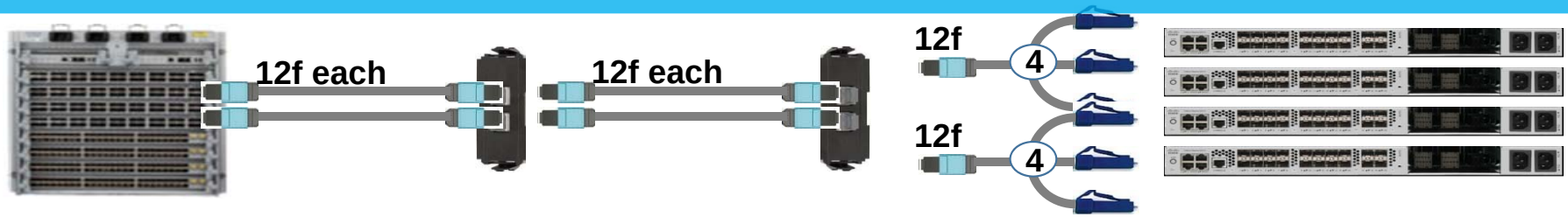


Cabling Infrastructure Breakout of 10G from 40G

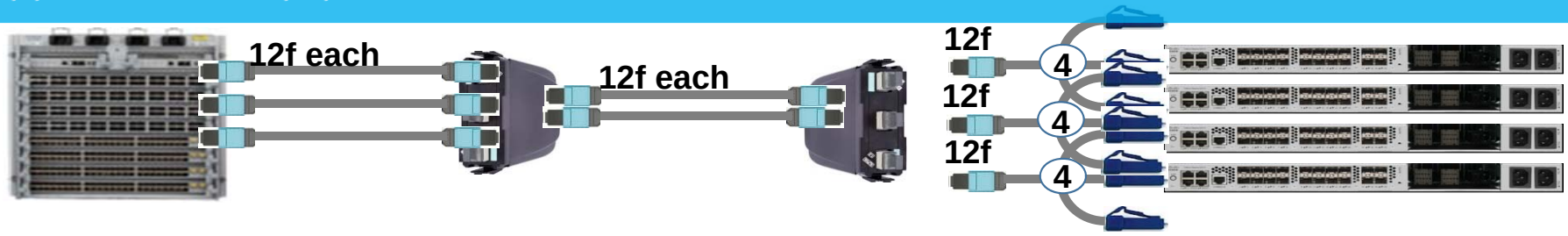
40G breakout to (4) 10G LC using existing 10G cabling



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

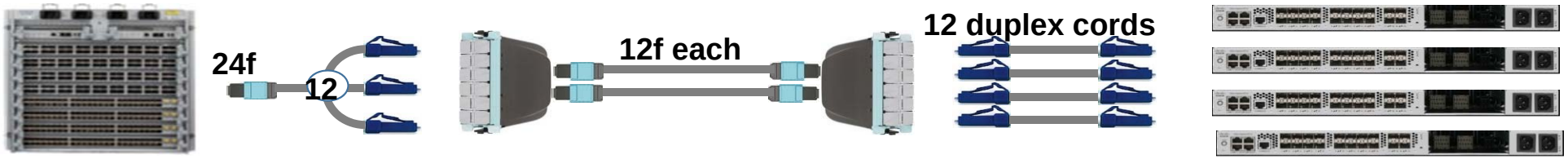


(3) 40G breakout to (12) 10G LC with 100% fiber utilization in trunk cables



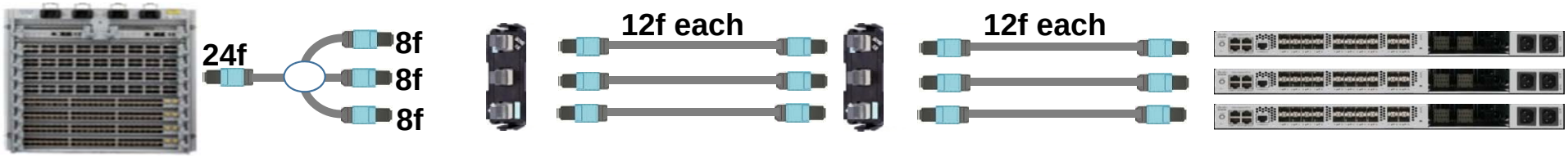
Cabling Infrastructure Breakout of 10G from 100G/120G

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

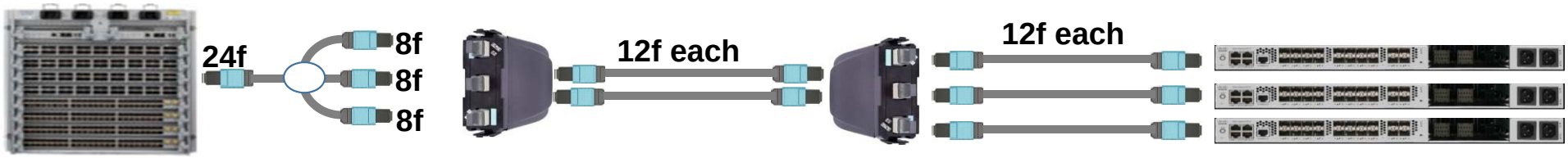


Cabling Infrastructure Breakout of 40G from 100G/120G

120G MPO breakout to (3) 40G MPO

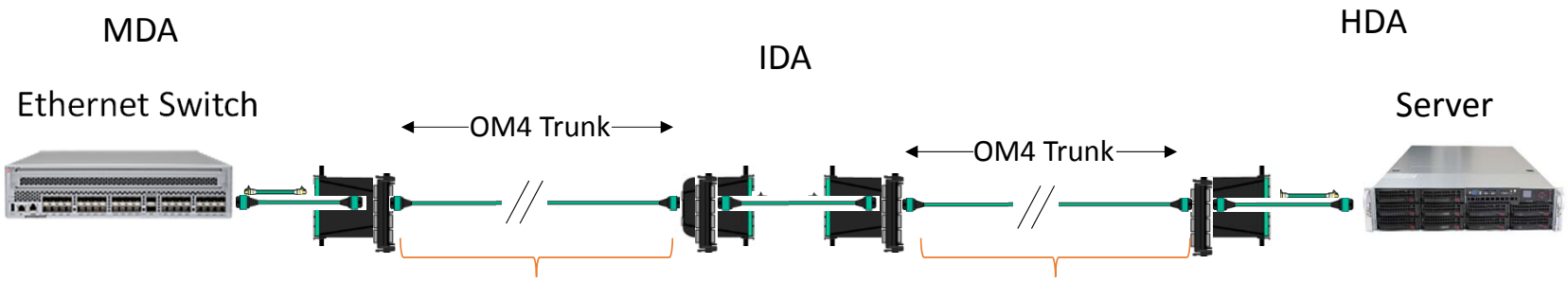


120G MPO breakout to (3) 40G MPO with 100% fiber utilization in trunk cables



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

100GBASE-SR4



Trunk cabling is retained

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

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

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