



*TOMORROW
starts here.*

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High Speed Data Networks - 40G, 100G and Beyond

BRKOPT-2116

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#clmel

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Agenda

- Trends / Introduction
- 40GE & 100GE Standards
- 40GE Transceivers and Cables
- 100GE Transceivers and Cables
- 40GE & 100GE and beyond
Inter DC consideration
- Summary



The Internet of Everything

Exponential Growth

- **Video, Mobile & Cloud** is Driving Traffic Growth
- Content & traffic patterns are becoming more dynamic and distributed
- **The Internet of Things** will accelerate traffic beyond recognition:
 - Radically increase volume
 - Dramatically change traffic patterns
 - Challenge traffic engineering and management
 - Demand new service definitions (SLAs)
- To keep pace, **Enterprise** and **Service Providers** need **agile solutions** that reduce complexity and TCO
- As demand for **bandwidth** continues to increase, there is a need for
 - **Higher speeds: 40G and 100G**
 - **Smaller size optics: Enables higher density**
 - **Lower cost/bit: Enables higher adoption**

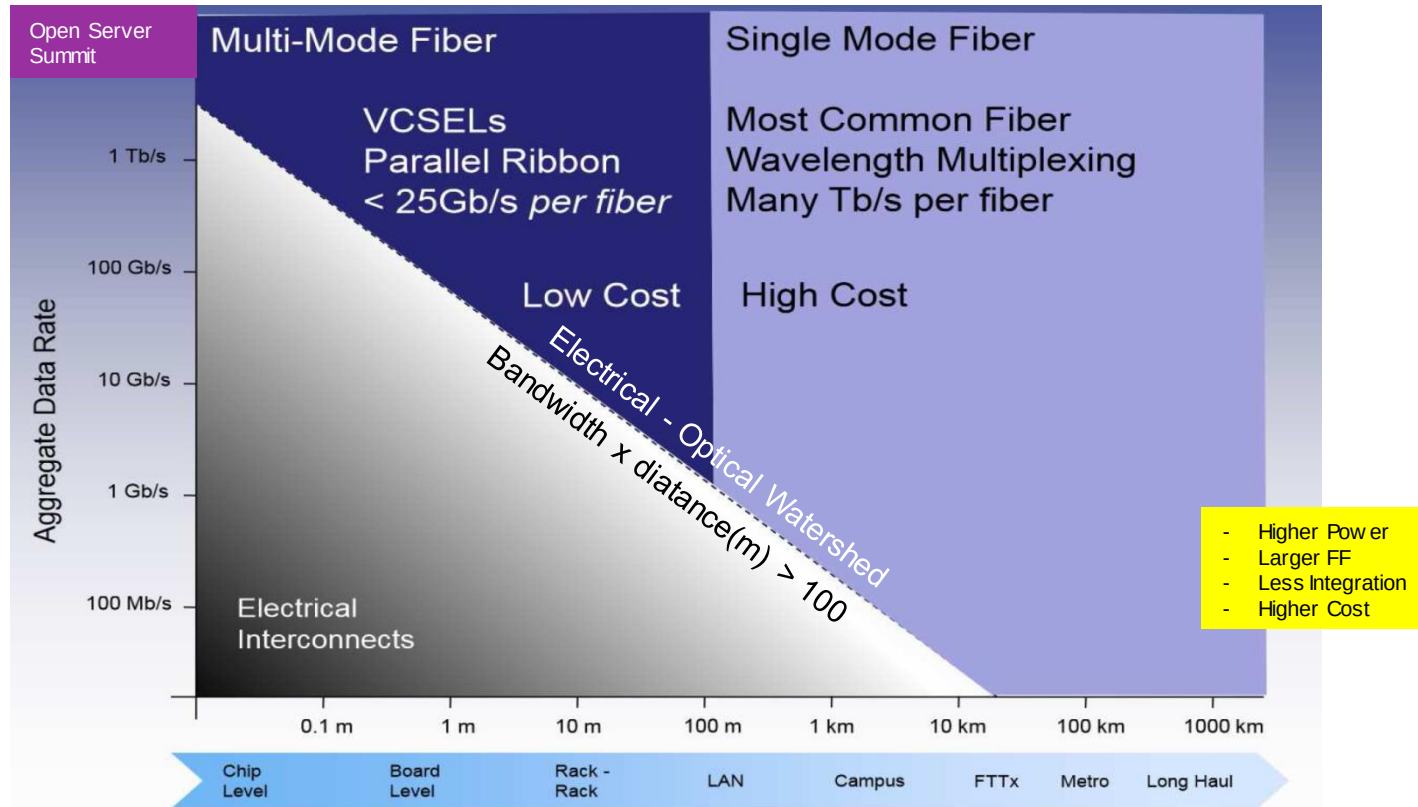


Industry Trends



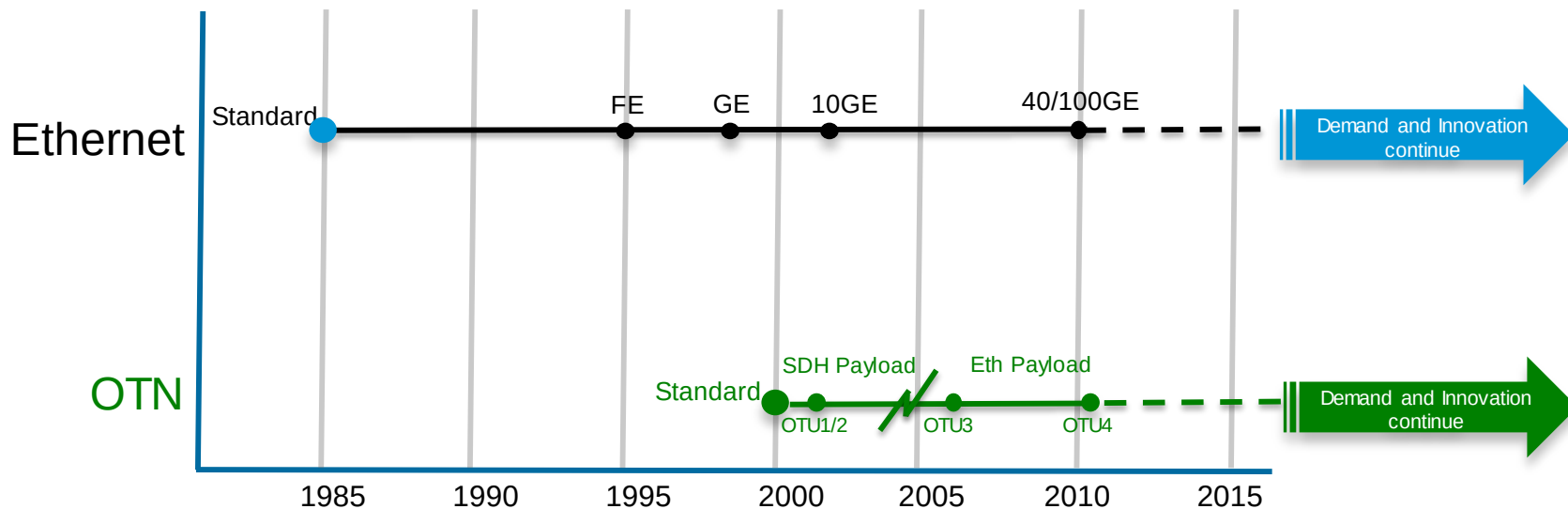
- Ethernet is a standard that continues to evolve and show innovation - FE - GE - 10GE - 40GE - 100GigE – 400GE-1TB?
- 2014: 25Gb/s at 3-5 m
- 2017: board-level photonics
- QSFP28 becoming defacto for high density 100G
- OTN aligned with Ethernet Speeds
- Cost, reach, size, power optimisation continues
- Dilemma copper vs optical for 400G and beyond
- OTN – choice for optical transport (framing or switching)
- Market need for flexible interfaces on client devices – pluggables long/short/DWDM interfaces
- More bandwidth per faceplate – how do we beyond current pluggables to support 5TB+

Application Space - Today

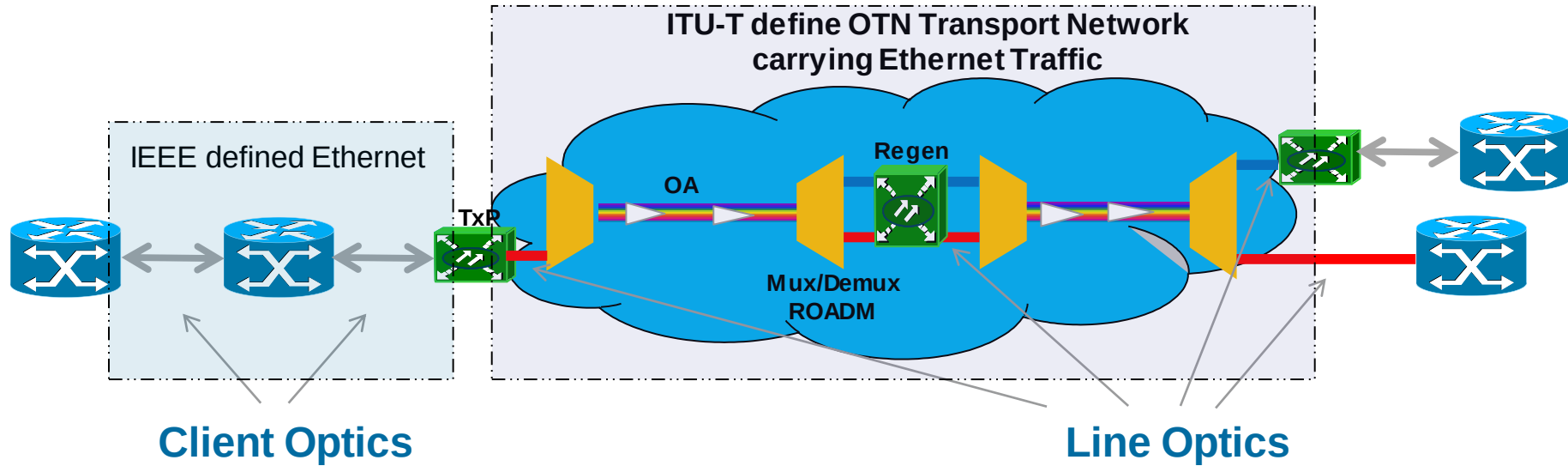


Ethernet and OTN Evolution

- Ethernet has undergone continual innovation since standardisation
- Transport systems evolving to 400G



40/100G Client and Transport Reference



- Within a building/campus (< 10km)
- Single I/F / Fibre (Grey optics)
- POS, OTN & Ethernet
- **Cost is King**



- Across country (1000s km)
- Multiple channels / Fibre (DWDM)
- OTN
- **Performance is king**

Optical Technology...

...Is the key enabler for systems to maintain pace with the requirements of the bandwidth pressures

Challenge

Form Factor Size reduction

Power reduction

Reach

Packaging simplification

The next speed (400G/1T)



Goal

Port Density increase

Port Density increase

System/network scaling

Increased Yield, lowers cost

System Scale, lower costs



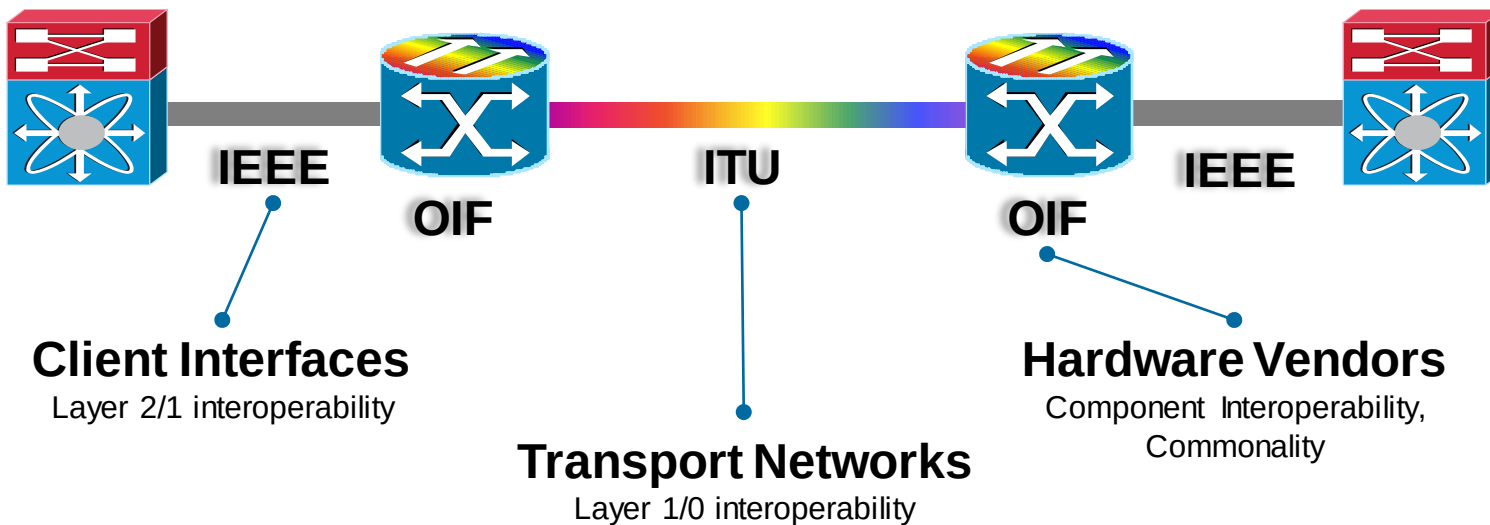
40GE and 100GE Standards

40G/100G Industry Standards

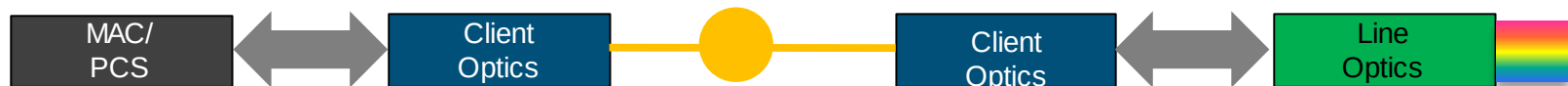
- IEEE 802.3ba: 40Gb/s and 100Gb/s Ethernet Task Force
 - 40G and 100G Ethernet
 - Physical interfaces for Backplane, Copper, Fibre PMDs
- IEEE 802.3bg: 40Gb/s SMF Ethernet Task Force
 - 40G Serial PMD optimised for carrier applications
- ITU Study Group 15: Optical and Transport Networks
 - OTU4 frame format
 - Single mapping for 40GE/100GE into OTU3/OTU4
 - OTL protocol enabling OTU3/4 over multi-lane (low cost) optics
- OIF: 100G Long-distance DWDM Transmission
 - Industry consolidation around a single 100G DWDM solution

100G Standards Alignment

- 100G standardisation coordinated among ITU, IEEE, and OIF
- Proactively eliminate interop issues encountered with 40G



40 and 100G Client and Line Perspective



Electrical I/F:

- 0-10"
- 1x,4x,16x Lanes
- 10->25G electrical

Client Optics:

- 0 to 2/10km
- Pluggable
- MMF and SMF

Line Optics:

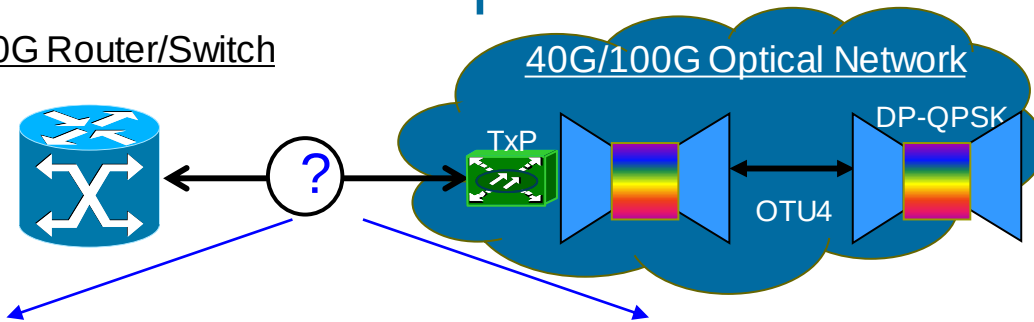
- Long Haul, DWDM
- OTN Protocol
- 1500+km

- Key Components:

- MAC/PCS – what happens after 25G electrical; interest in 25GE MAC/MSA (server to ToR) enable 4x25/100G up
- Electrical Interface (to pluggable Client optics)
- Client Optical Interface
- Line (DWDM) Optical Interface

40/100G Client Interface Options

40G/100G Router/Switch



Native Ethernet

- Transport maps ethernet to OTN
- Lowest cost .. but perceived lack of OAM
- IEEE 802.3ba added BIP error check
 - PCS_SD_BER, TCA_PCS_BER, PCS Lane BIP-8 monitor
- SONET/OTN like error monitoring
 - SF/SD BER thresholds, etc

OTN “Short Reach” Client

- Alignment on client optics
- ITU added support for parallel optics:
 - OTL4.4, OTL4.10 OTL3.4, etc
- Can run OTN clients (both 40G and 100G) over ‘Ethernet’ optics.
- OTL added to support parallel optics

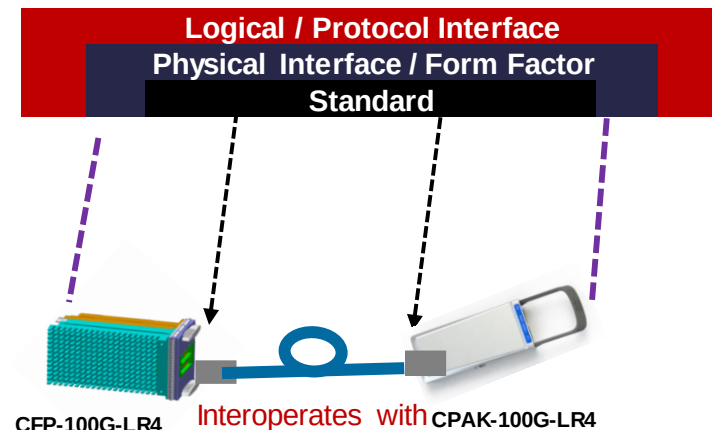


Industry Developments

- 802.3bm Task force goal of group is to lower 100G costs. (4x25G Electrical, 4x25G for MM)
 - No agreement on low cost 100G SM
 - Industry with non standard optics
- 802.3bs 400G in IEEE – 4x100, 8x50, 16x25 data rates (4x100 more promising)
- 802.3bj (backplane – electrical/optical 4x25)=100G backplane
- Non standard optics proliferating proposals for 500m on SMF.
 - 100G Advanced modulation –
 - 100G DMT - single wavelength advanced modulation using Discrete Multi-Tone
 - 100G PAM4 - advanced modulation using Pulse Amplitude modulation
 - CWDM - 4x25G wavelengths
 - 100G PSM4 - 4x25G parallel fibre
- 25G CFI – call for interface new MAC / Ethernet rate (server or EoR interface)
- Two key drivers:
 - 1) Advanced modulation will fundamentally lower complexity/cost (PAM, DMT)
 - 2) New technologies like CMOS Photonics may alter costs (CWDM, PAM)

IEEE Standard vs MSA Form-factor

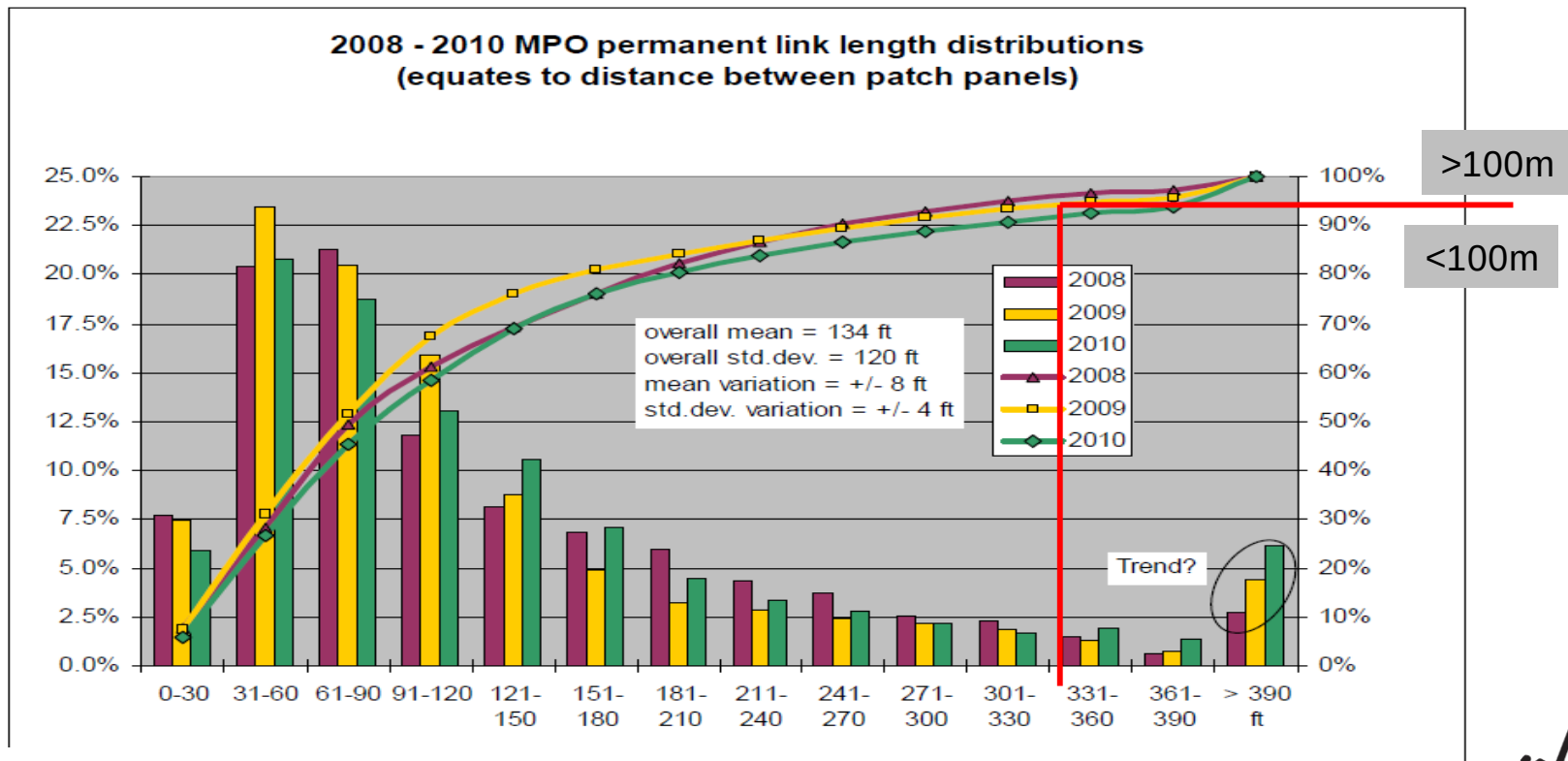
- IEEE defines physical network interfaces i.e PMDs
 - 10GBASE-SR, 40GBASE-SR4, 100GBASE-SR10 etc
- MSA (multi-source agreements) define transceiver form factors
 - CFP, QSFP, SFP+, X2 etc
 - defined by a group of transceiver vendors based on technology availability and roadmap
- PMDs of the same speed/reach/ protocol must interoperate, irrespective of the form factor
 - X2-10GB-SR interoperates with SFP-10G-SR, both being defined by the 10GBASE-SR physical interface
- Focus on IEEE specification instead of form factor for interoperability
 - Optics form factor decisions driven by the port density requirements vs reach availability



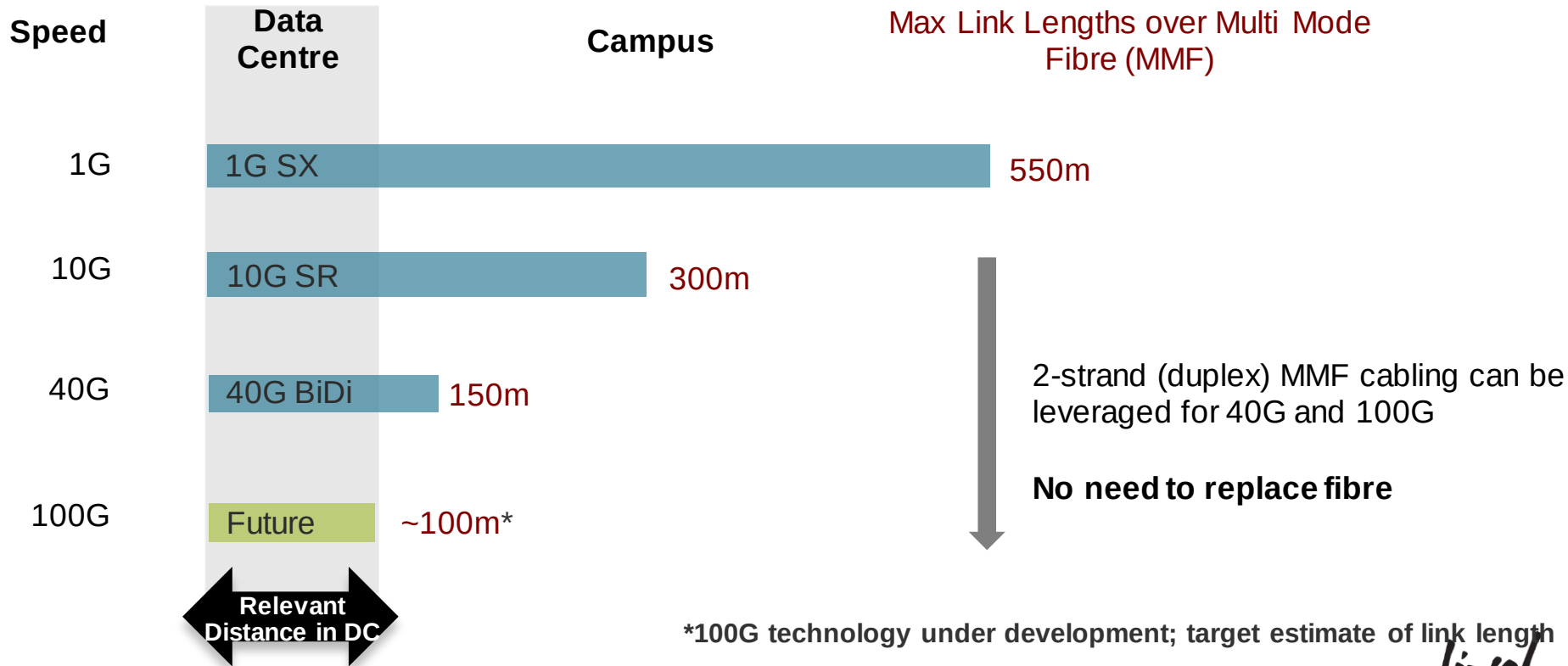
A long-exposure photograph of a city street at night. The background shows tall buildings with lit windows and a pedestrian bridge. The foreground is dominated by vibrant, multi-colored light trails from moving vehicles, creating a sense of motion and energy. The text "40GE Transceivers and Cables" is overlaid in the center.

40GE Transceivers and Cables

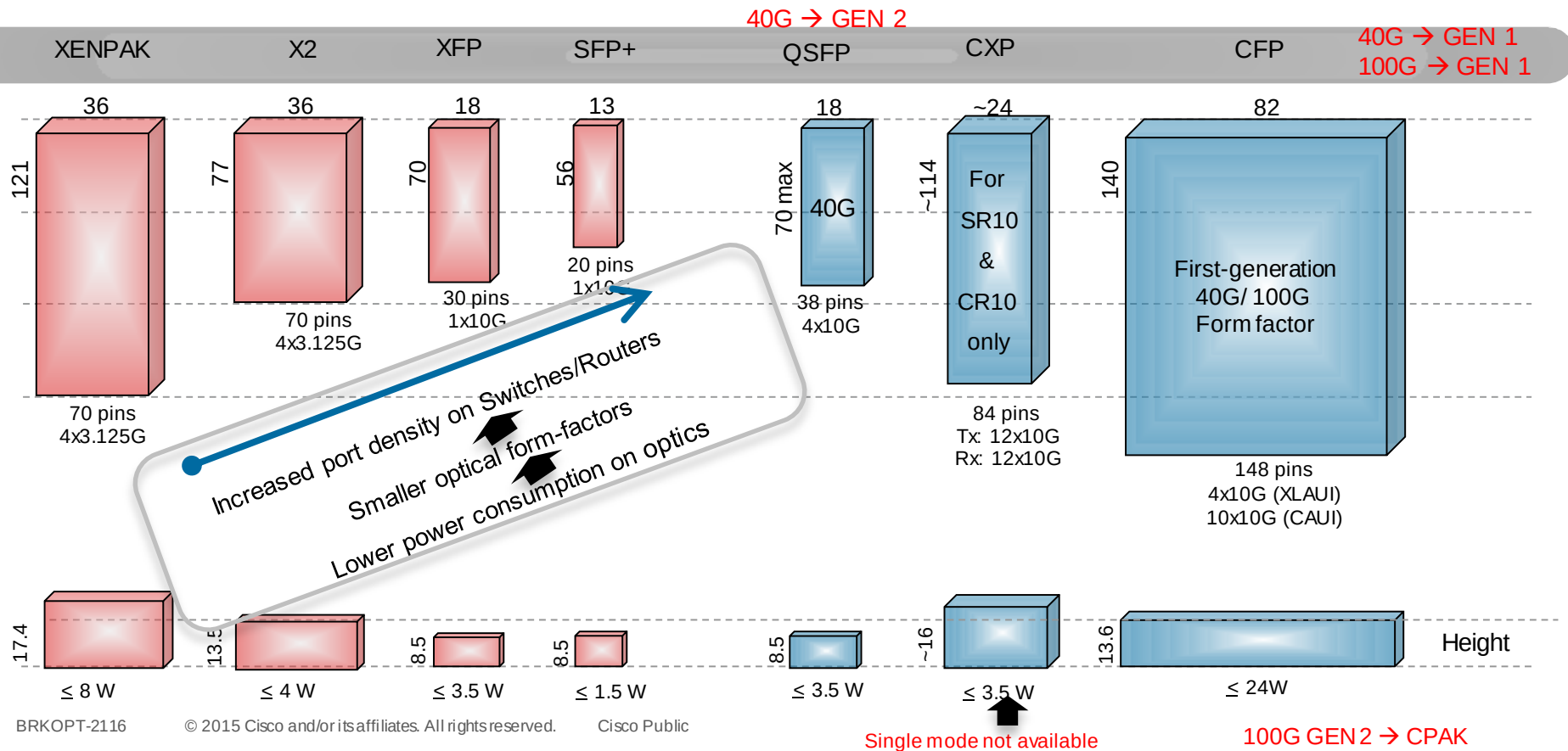
Data Centre Permanent Link (Trunk) Distributions (2008-2010)



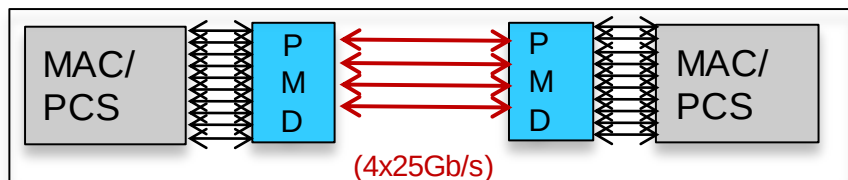
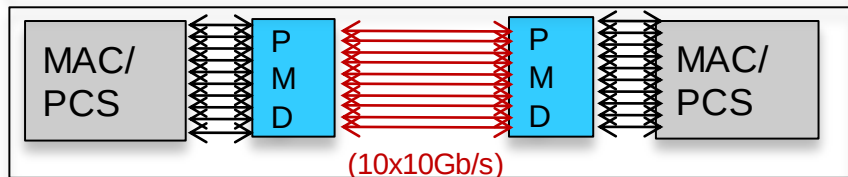
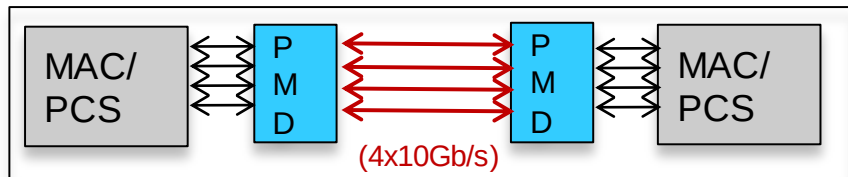
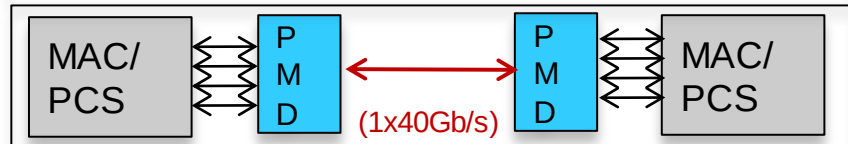
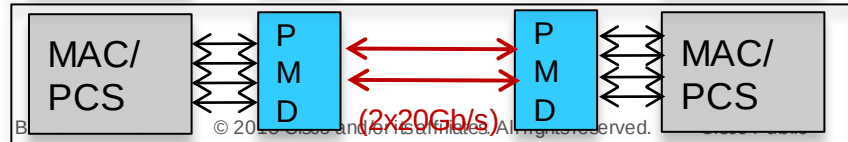
Multimode Fibre is FORWARD and BACKWARD Compatible



10G/ 40G Transceiver Form Factors



Parallel Data Streams



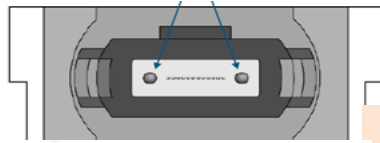
Electrical data lane >25Gb/s (black)
w/ improve efficiency & density

↔ Electrical data lane 10Gb/s (black)
↔ Optical data lane (red)

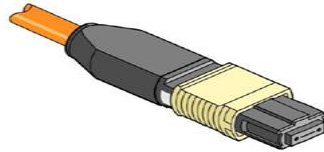
- Device interfaces in Switches & Routers (ASICs) currently cannot handle single 40Gb/s and 100Gb/s data streams (only 10Gb/s -> 25Gb/s)
- IEEE has defined 'parallel lanes' to handle flow of data
- Multi-lane Distribution (in the PCS layer) provides a simple way to map 40G/100G to physical interfaces of different lane widths – with Virtual lanes
- Data from any particular virtual lane will reside on the same electrical and optical lane across the link – No skew introduced between bits within the virtual lane

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Parallel Ribbon Fibre for 40G/100G Interfaces



< 40G MPO interface
(one row of 12 fibres)



40G 12-strand ribbon fibre
(4 fibres in the middle left unused) >

< MPO Optical Connector



< MPO to MPO patch cable

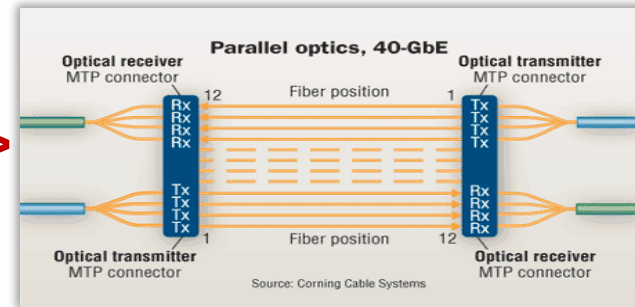
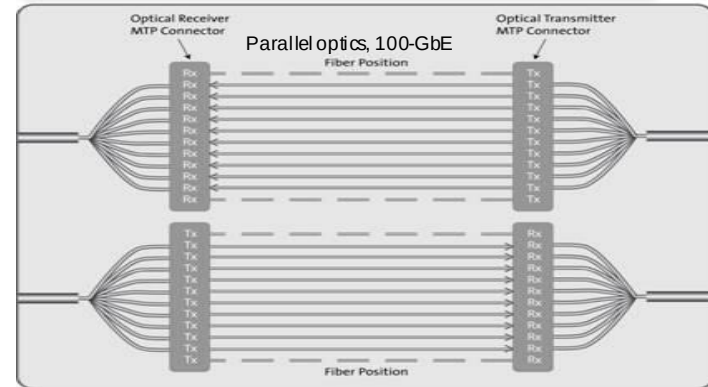


< Inside a ribbon fibre



< 100G MPO interface
(2 rows of 12-fibres)

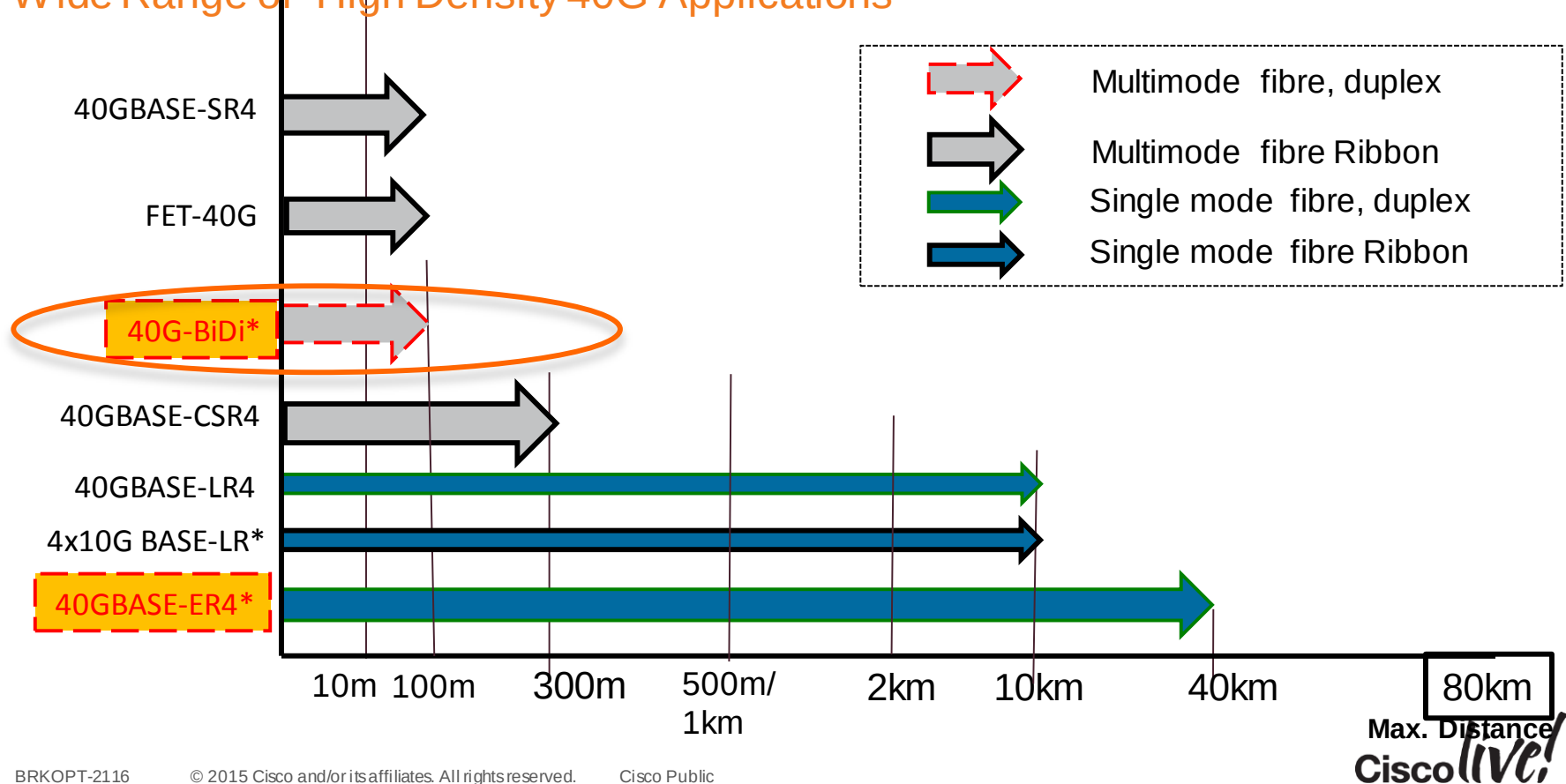
100G 24-strand ribbon fibre
(4 fibres in the left unused) >



MPO is a generic name for a ribbon optical connector, while MTP is a brand name

Cisco 40G Portfolio

Wide Range of High Density 40G Applications



40GE: QSFP-40G Portfolio

Key Specs	QSFP 40G-4X10GLR
Standard	10GBASE-LR
Connector	MPO-12
Reach	≤ 10 km
Fibre	Single Mode ribbon
Power Consumption	<3.5W
Features	Interoperability with 4x10G LR mode leveraging Silicon Photonics

Key Specs	QSFP-40G-LR4 (IEEE)
Standard	40GBASE-LR4
Connector	LC
Reach	≤ 10 km
Fibre	Single Mode duplex
Power Consumption	≤ 2.5 W
Features	Uses SM Duplex Fibre

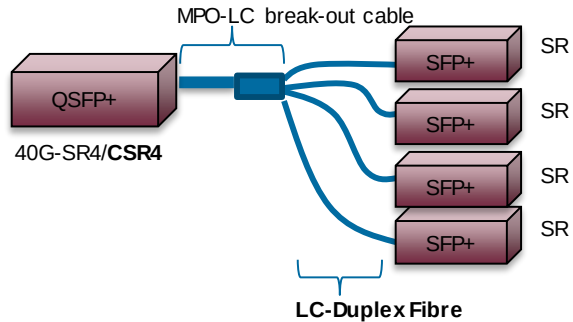
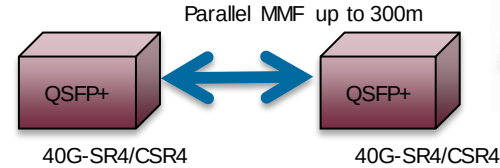
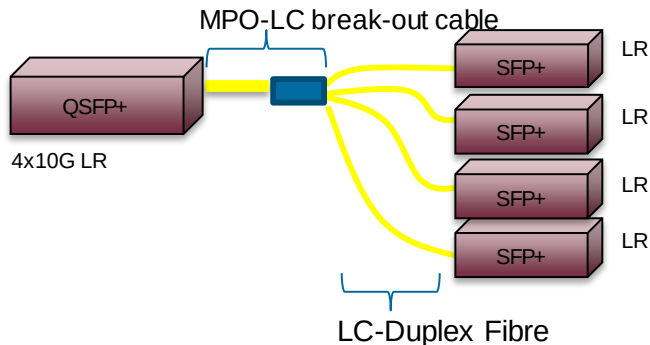
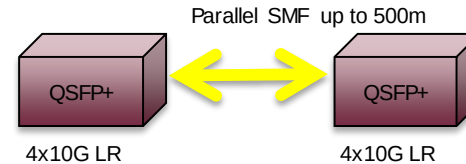
Key Specs	QSFP-40G-CSR4
Standard	4x10GBASE-SR
Connector	MPO-12
Reach	OM3: ≤ 300 m OM4: ≤ 400 m
Fibre	Multi Mode ribbon
Power Consumption	1.5W
Features	10G-SR (300m) to 40G-CSR4 (300m) migration

Key Specs	QSFP-40G-SR4 (IEEE)
Standard	40GBASE-SR4
Connector	MPO-12
Reach	OM3: ≤ 100 m OM4: ≤ 150 m
Fibre	Multi Mode ribbon
Power Consumption	1.5W
Features	Configurable to run in 4x10G SR mode

SR4 and CSR4 QSFP40G INTEROPERABILITY

INTEROPERABILITY	10GBASE-SR (300m OM3/ 400m OM4 MMF)	Cisco QSFP-40G-SR4 ² (100m OM3/ 150m OM4 MMF)	Cisco QSFP-40G-CSR4 ³ (300m OM3/ 400m OM4 MMF)	IEEE 40GBASE-SR4 ¹ (100m OM3/ 150m OM4 MMF)
10GBASE-SR (300m OM3/ 400m OM4 MMF)				
Cisco QSFP-40G-SR4 ² (100m OM3/ 150m OM4 MMF)				
Cisco QSFP-40G-CSR4 ³ (300m OM3/ 400m OM4 MMF)				
IEEE 40GBASE-SR4 ¹ (100m OM3/ 150m OM4 MMF)				

QSFP40G 40G-SR & QSFP 4x10G LR Interoperability



40G QSFP Cables and Adapters



QSFP TO SFP/SFP+ adapter

- QSFP adapter supports one SFP or SFP+ module
- Use case: 10G connectivity on a 40G port

40G Copper Cables:

- QSFP to QSFP 40G for 1m thru' 10m
- QSFP to 4 X SFP10G Breakout cables



40G Optical Cables (AOC):

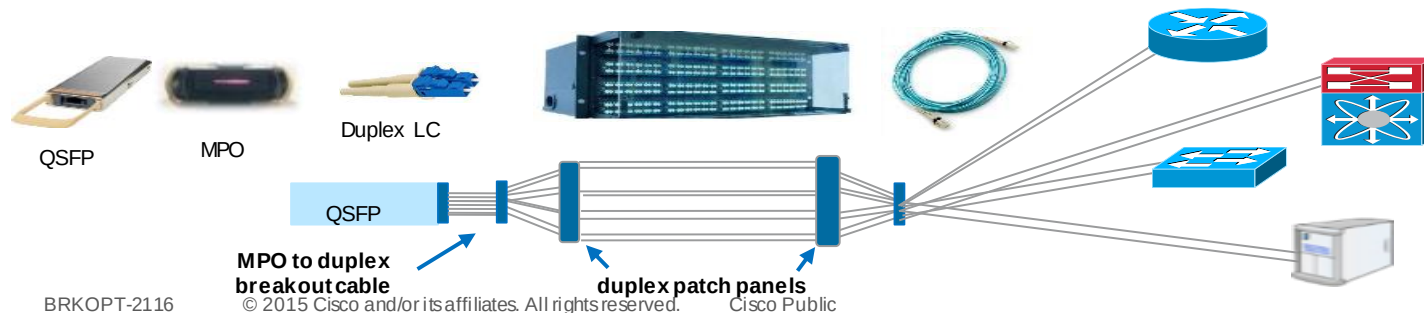
- QSFP to QSFP 40G
 - 1m thru' 10m
 - 15m
- QSFP to 4 X SFP10G Breakout c 10m



40G Break-out Distance

Distance based on optic and media used

40G Optic	Media	Distance	10G Optic
40G CSR4	Multi-Mode Fibre	82-400m	SFP-10G-SR-X
40G SR4		30-150m	SFP-10G-SR
FET-40G		30-150m	SFP-10G-SR
FET-40G	Multi-Mode Fibre	30-150m	FET-10G
40G Twinax	Copper	7-10m	N/A
40G Active Optical Cable (AOC)	Fixed optical	1-10m	N/A



Bi-Directional QSFP40G-SR

- Short reach transceiver with 2 channels of 20G, each transmitted and received over a multi-mode fibre
- 100m with OM3 grade fibre
- Electrical interface: IEEE 802.3ba Compliant
- Power consumption < 3.5w
- Use of duplex multimode fibre allows customers to migrate from 10G to 40G with minimal capital investment
- QSFP-BIDI to QSFP-BIDI connection only – No interoperability support with QSFP-SR4 or 10G SR
- **Cisco exclusive transceiver**

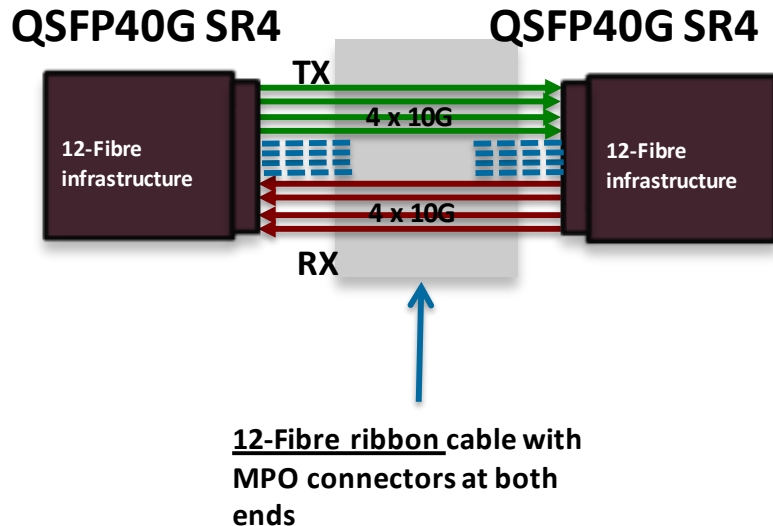
QSFP+ SKU	Center Wavelength (nm)	Cable Type	Cable Distance (m)
QSFP-40G-SR-BD	850nm	LC Duplex	100m (OM3) 125m (OM4)



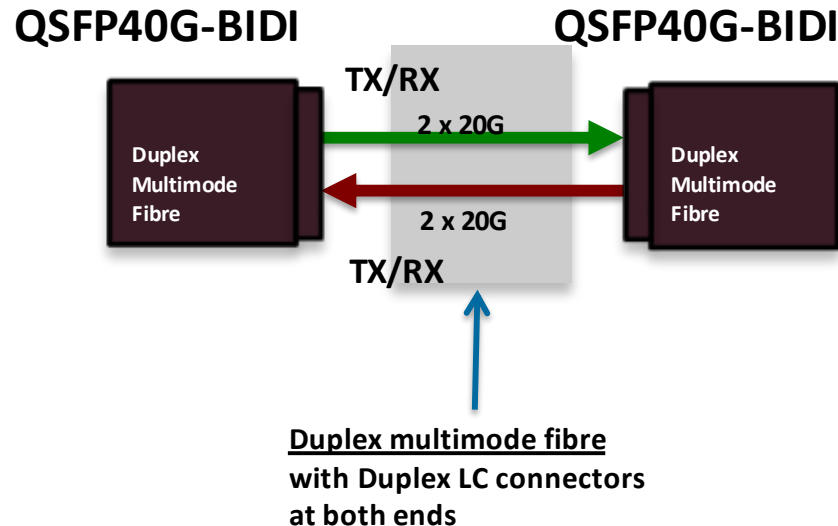
Cable Type	Core Size (Micron)	Modal Bandwidth (MHz*Km)	Cable Distance	Comments
MMF	50.00	500 (OM2)	30m	
		2000 (OM3)	100m	Connector loss budget for OM3 Fibre is 1.5dB
		4700 (OM4)	125m	Connector loss budget for OM4 Fibre is 1.0dB (Engineered Link)
		OM4+	150m	Connector loss budget for OM4+ Fibre is 1.0dB (Engineered Link) Reference OM4+ Fibre: Panduit Signature Core Fibre: http://www.panduit.com/en/signature-core

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QSFP40G-BIDI Value Proposition



Higher cost to upgrade from 10G to 40G due to 12-Fibre infrastructure

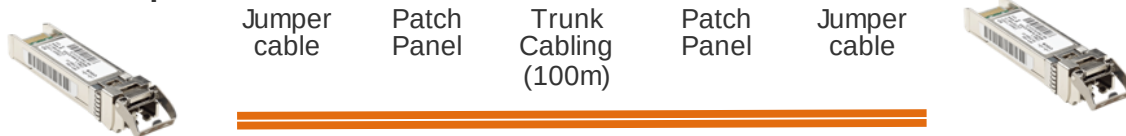


Use of duplex multimode fibre lowers cost of upgrading from 10G to 40G by leveraging existing 10G multimode infrastructure

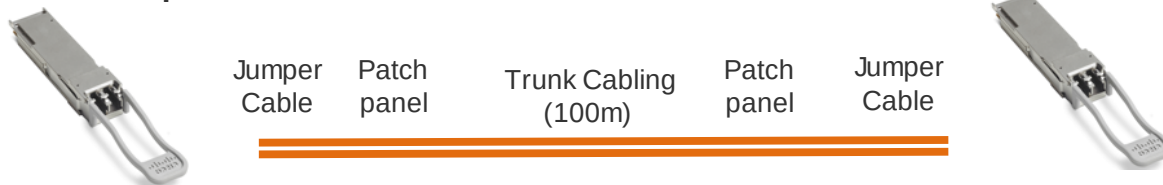
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10G Fibre Infrastructure Reuse: BiDi vs SR4

10G Optical Link



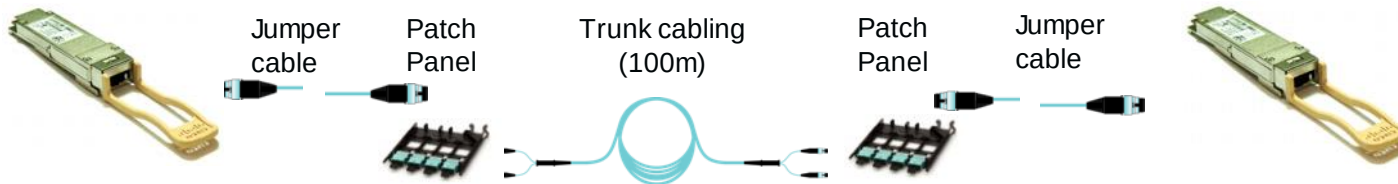
40G Optical Link with BiDi



40 GbE BiDi
Reuse 10G SR
fibre
infrastructure?



40G Optical Link with SR4



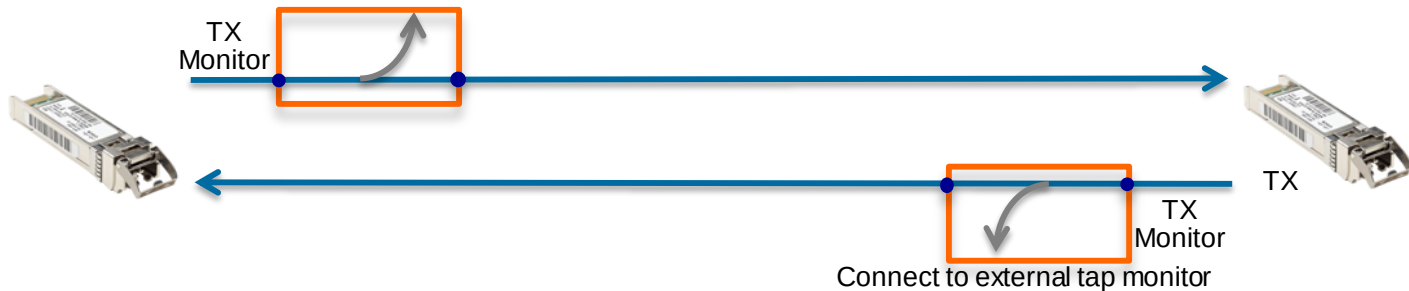
40GbE SR4
Reuse 10G SR
fibre
infrastructure?



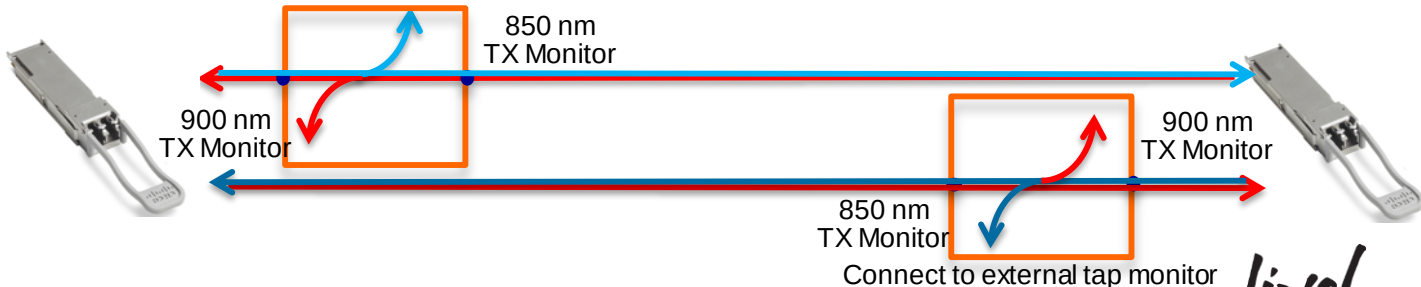
Optical Monitoring with a BiDi Optic

- QSFP BiDi optics does not include Digital Optical Monitoring
- External tap monitoring is feasible for a BiDi*, and similar to 10G SR
Use 2x2 splitters for BiDi rather than 1x2 splitter for 10G SR or other uni-directional links
Neither 10G SR nor the 40G BiDi have link budget allocation for external tap monitoring
Link margins are used to determine if external monitoring is feasible

10G SR Tap Monitoring

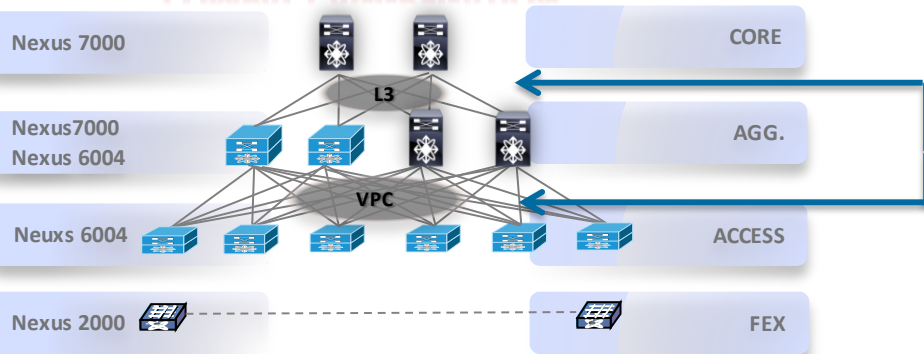


40G BiDi Tap Monitoring

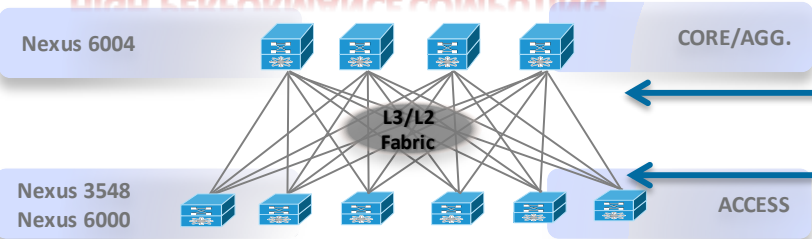


QSFP40G BiDi: Targeted Solutions

COMPACT AGGREGATION

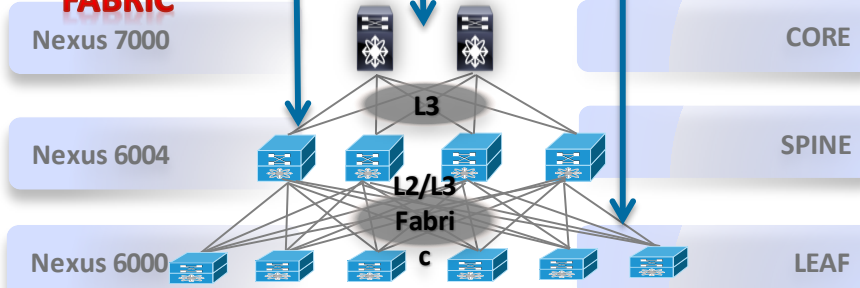


HIGH PERFORMANCE COMPUTING



QSFP-BIDI Optics

LARGE SCALE FABRIC

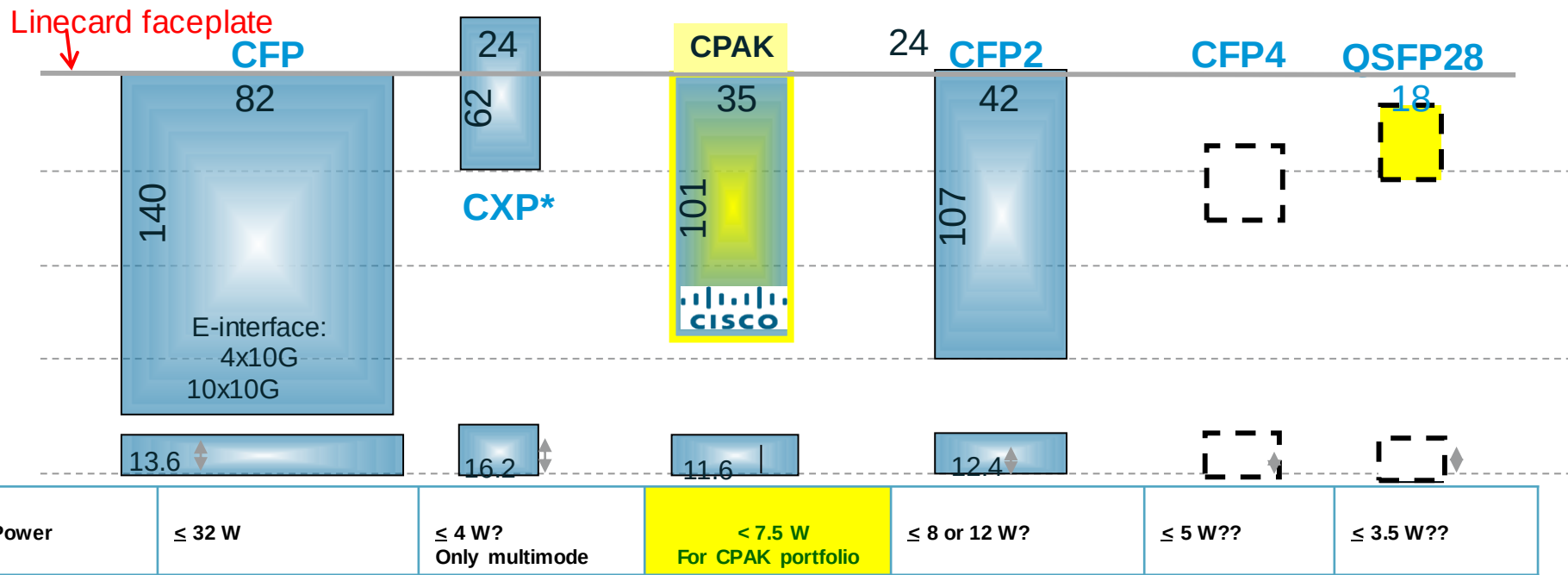


QSFP-BIDI Optics



100G Transceivers and Cables

100G Module Form Factors Evolution



The technology that enables Cisco CPAC is CMOS Photonics

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100G Client Optics Comparison



Features		CXP	CFP	CFP2	 CPAK
Front Panel Bandwidth		1.5Tb/s	200Gb/s	800Gb/s	1Tb/s
Power Dissipation (W)		3.5W	24W	12W	7.5W (CPAK- LR4: <6.75W)
Fibre Type		MMF	SMF & MMF	SMF & MMF	SMF & MMF
IEEE Reach Availability	SR10	In Production	In Production	Sampling	In Production
	LR4	No	In Production	Sampling	In Production
	10x 10GE-LR	No	No	?	Planned
	ER4	No	In Production	?	Planned

Competition plans to use CXP or CFP2. Both approaches have a number of disadvantages.

CXP

- Only supports MMF
- Only offers SR10
- Cannot deliver LR, ER

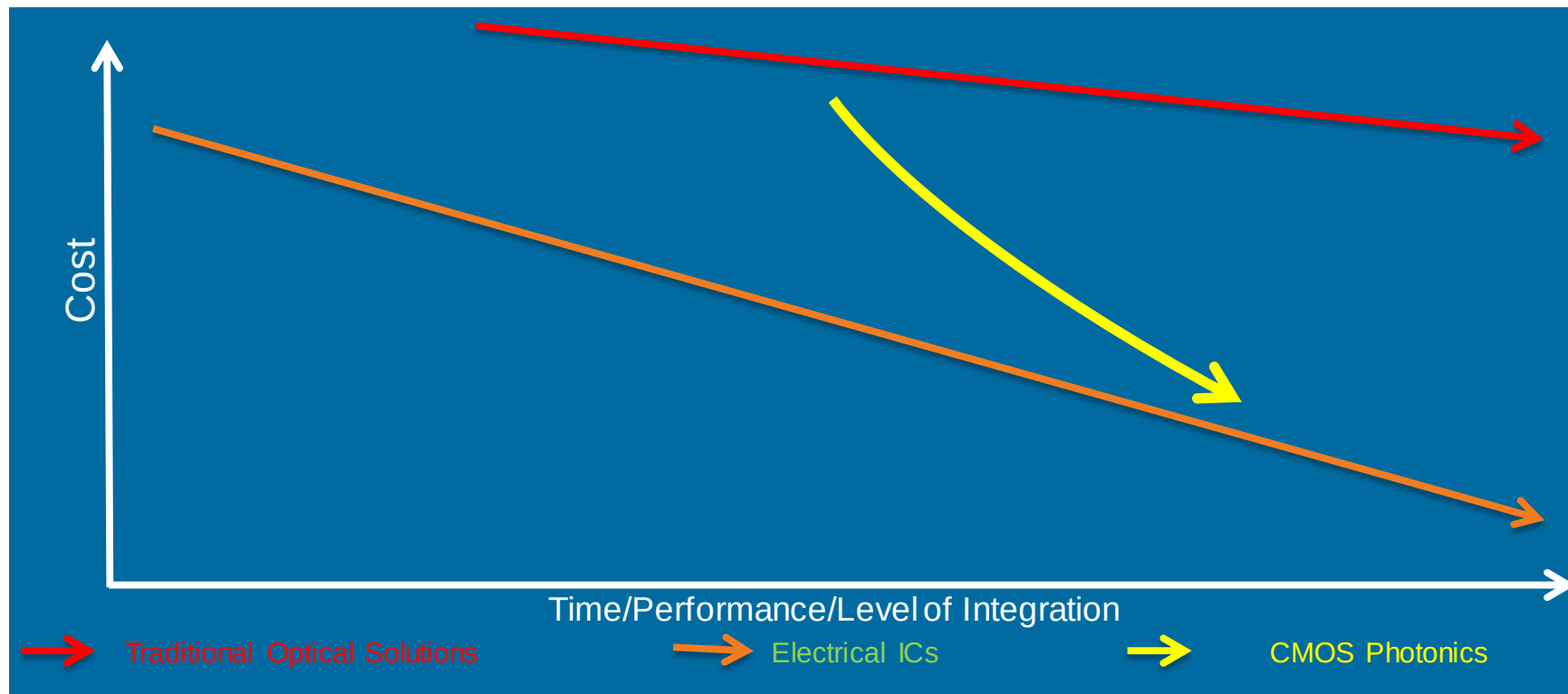
CFP2

- Not yet in production, MSA just concluded
- Larger in size than CPAK
- Higher power dissipation than CPAK
- Timing for supported reaches (SR10, LR4, ER4) - ?

**Cisco CPAK, the highest density, lowest power consuming 100G module available,
w/ complete portfolio of IEEE 100GBASE reaches
CPAK is shipping today on 5 Cisco platforms and is already deployed in customer networks**

Relative Cost of Optics and Electronics

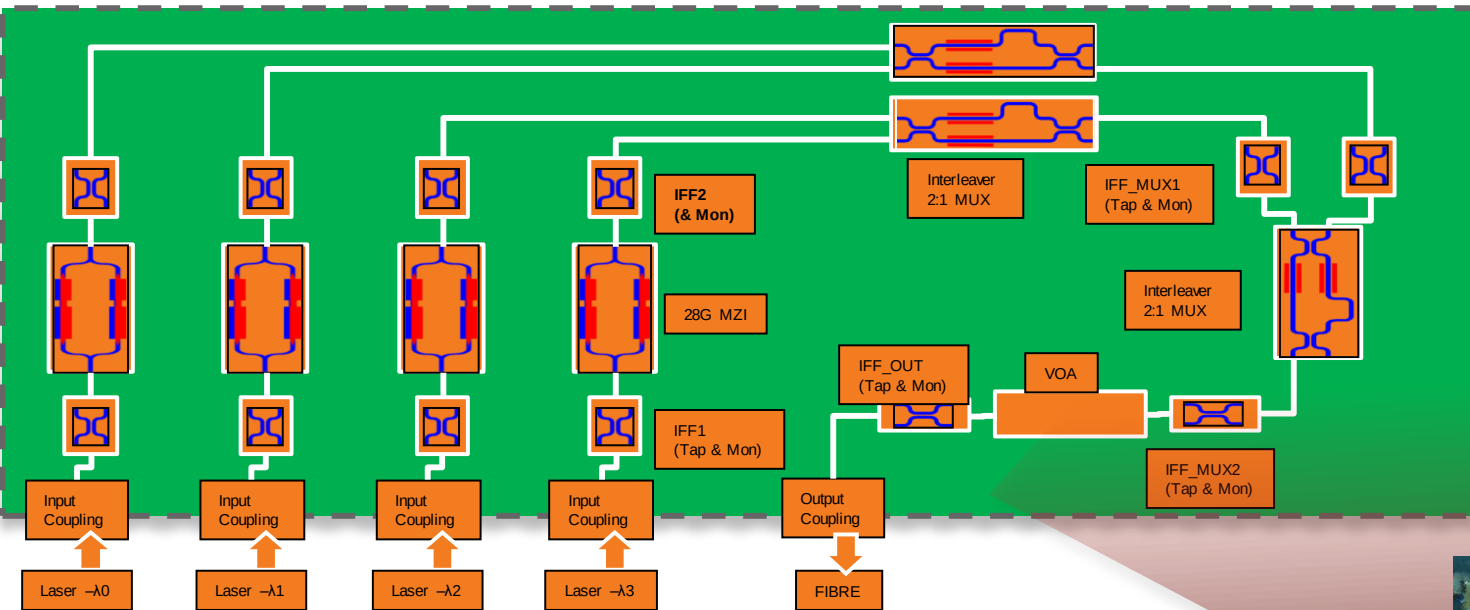
Putting Optics on the Same Path as Electronics



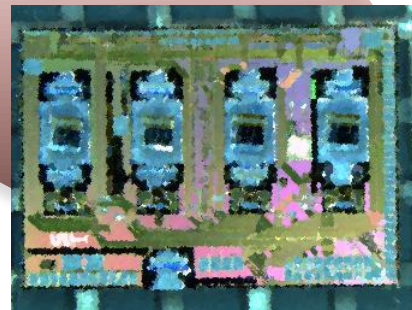
Applying Moore's Law to Optics

CMOS Photonics Circuit

Highly Integrated and Highly Repeatable in Performance and Production



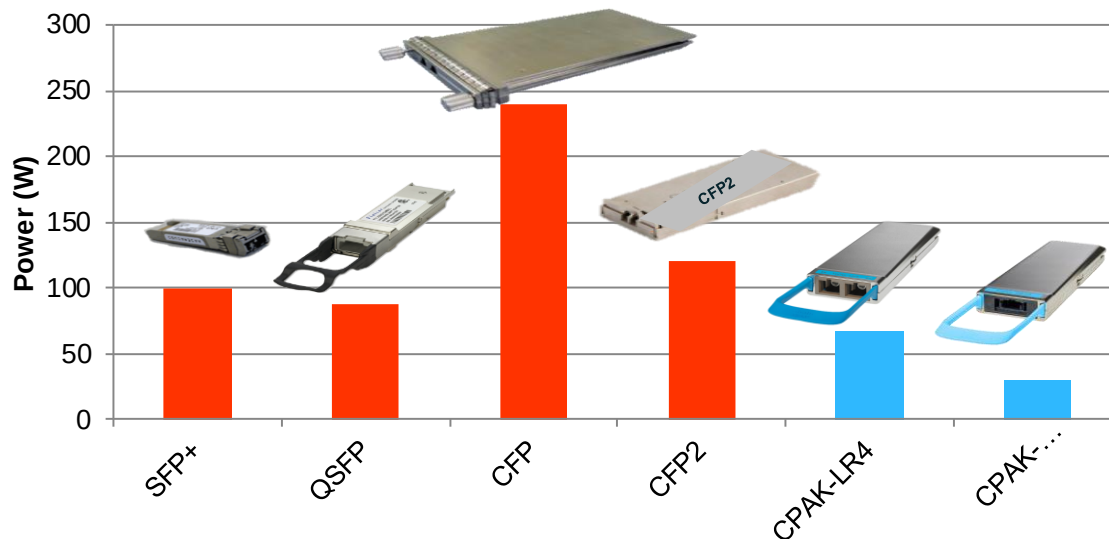
Integrating over 32 optical elements in a single CMOS chip
Wafer scale manufacturing
Wafer scale repeatability



Compare the Power for 1Tb/s

CMOS Photonics is Bringing Down the Power of Bandwidth

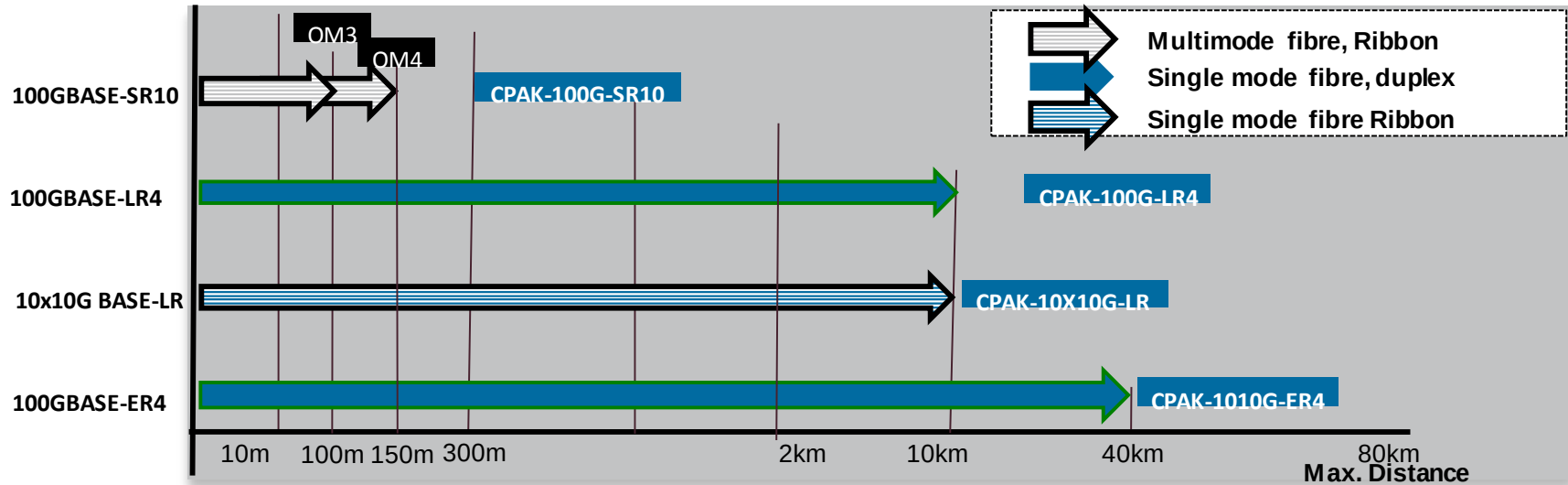
Power Dissipation for 1Tb/s



Cisco CPAK Provides the Industry's Most Efficient Bandwidth

Cisco CPAK 100G Product Portfolio

Wide Range of High Density 100G Applications



Cisco Product ID	IEEE Standard Compliance	Max Power Dissipation	Reach	Fibre Type	Optical Connector
CPAK-100G-SR10	100GBASE-SR10 2X 40GBASE-SR4 10x 10GBASE-SR	< 4W	<100m OM3 <150m OM4	MMF	MPO-24
CPAK-100G-LR4	100GBASE-LR4	< 6.75W	< 10km	SMF	Duplex SC
CPAK-10x10G-LR	10x 10GBASE-LR	< 4.5W	< 10km	SMF	MPO-24
CPAK-100G-ER4	100GBASE-ER4	< 7.5W	< 40km	SMF	Duplex SC

CPAK-100G-LR4

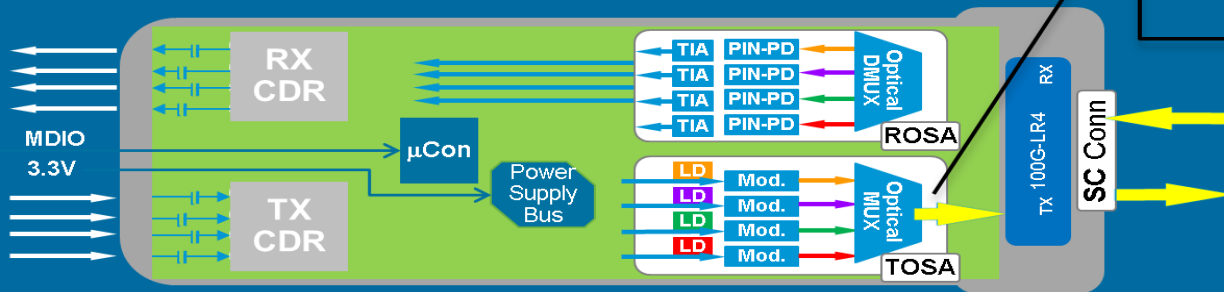
KEY

- LD = Laser Diode
- PD = Photo Diode
- Mod. = Modulator
- TIA = Transimpedance Amplifier

- CDR = Clock & Data Recovery
- TOSA=Transmitter Optical SubAssembly
- TOSA=Transmitter Optical SubAssembly

TOSA enabled by Cisco's
CMOS Photonics
Technology

OIF-VSR28
Electrical Interface



FEATURES

IEEE 100GE Compliance

Interoperates with other 100GBASE-LR4 module

CFP & CFP2

Low power CMOS Photonics TOSA

CMOS Photonic Integrated Modulators/Mux

CMOS CDR on each channel

Supports DOM

Key Specs	CPAK100G-LR4
Standard	100GBASE-LR4
Connector	Duplex SC
Reach	< 10km
Fibre	Single Mode Fibre
Max Power Consumption	<6.75W
Typical Power Consumption	<5.5W

100GE: CPAK-100G Portfolio Leveraging Silicon Photonics

Key Specs	CPAK100G- 10X10GLR
Standard	10GBASE-LR
Connector	MPO-24
Reach	≤ 10 km
Fibre	Single Mode
Power Consumption	<5W
Features	Configurable to run in 10x10GLR or 2x(4x10GLR) mode, 2 lanes per laser

Key Specs	CPAK100G-LR4
Standard	100GBASE-LR4
Connector	SC
Reach	≤ 10 km
Fibre	Single Mode
Power Consumption	≤ 7.5 W
Features	Up to 10 km reach on SMF

Key Specs	CPAK100G-ER4
Standard	100GBASE-ER4
Connector	SC
Reach	≤ 40 km
Fibre	Single Mode
Power Consumption	< 7.5W
Features	Up to 40 km reach on SMF

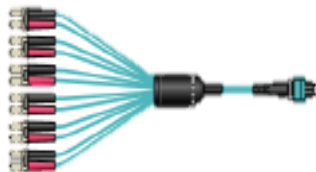
Key Specs	CPAK100G-SR10
Standard	100GBASE-SR10
Connector	MPO-24
Reach	OM3: ≤ 100 m OM4: ≤ 150 m
Fibre	Multi Mode
Power Consumption	≤ 4.5 W
Features	Configurable to run in 10x10GSR or 2x40GSR4 mode

“Anyport” 100 Gb CPAK Line Card Solution

Breaking the Fixed-Port Paradigm with CPAK

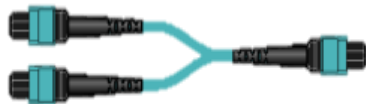
One CPAK Line Card Can Support 100G, 40G & 10G

10G Ports
Router/ Switching
Platform

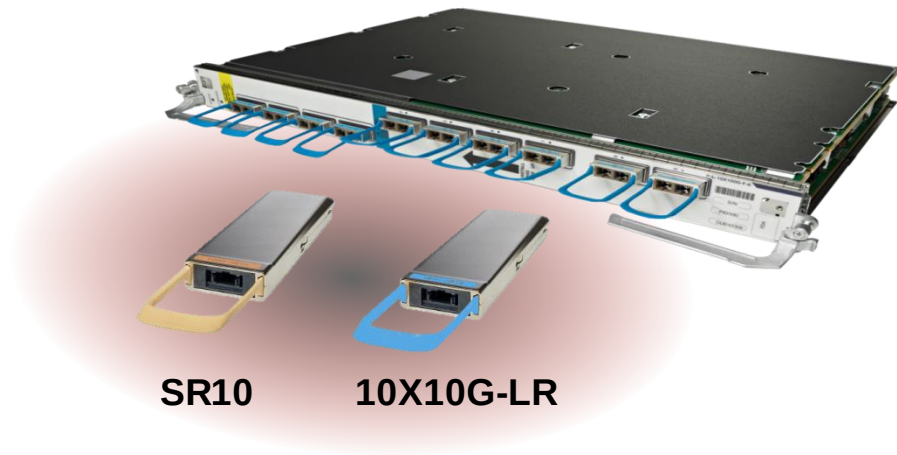


MPO-24 to 10x Duplex LC
SMF or MMF

40G Ports
Router / Switching
Platform



MPO-24 to 2x MPO-12
SMF or MMF



SR10

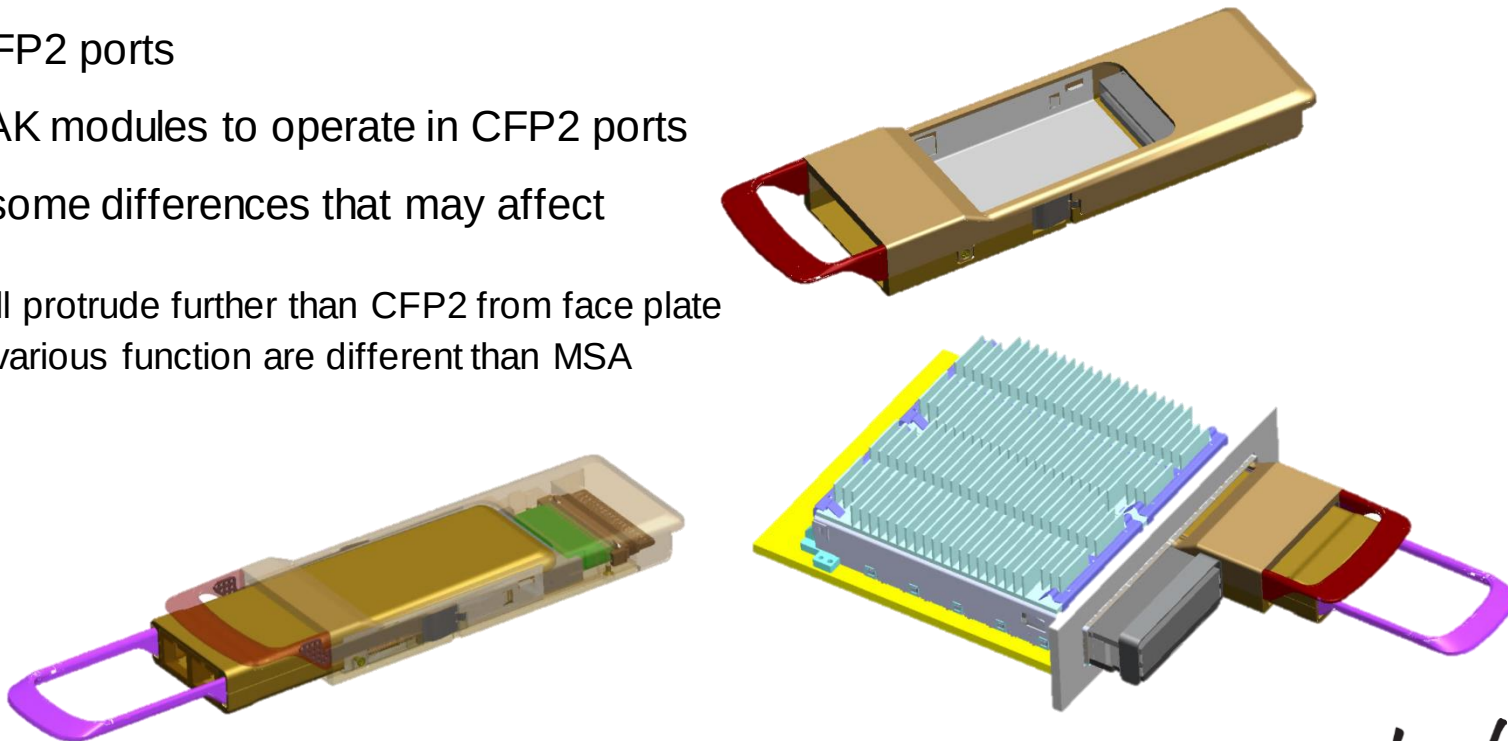
10X10G-LR

Extend the investment of a single line card to manage migration from 10G
and 40G to 100G

CPAK to CFP2 Adapter

Allows you to take advantage of CMOS Photonics in CFP2 platforms

- Will fit in CFP2 ports
- Allows CPAK modules to operate in CFP2 ports
- There are some differences that may affect platforms
 - Module will protrude further than CFP2 from face plate
 - Timing of various function are different than MSA



Typical Client Signal Reach Summary

40 and 100 GbE

100GBASE-CR10
40GBASE-CR4

Copper Cable Assembly

7m

100GBASE-SR10
40GBASE-SR4

Parallel Fibre OM3/4 ONLY

100m

QSFP40G-BiDi

Multimode Fibre

100m

DATA CENTRE
Intra Office
ONLY

NEW IEEE 802.3bg
40GBASE-FR
2Km

100GBASE-LR4
40GBASE-LR4
10Km

100GBASE-ER4
ONLY 100G
40Km

Copper

Multi Mode

Single Mode

10 GbE

1-10m
SFP+ direct attach

15m
10GBASE-CX4
(IB cabling)

100m
10GBASE-T
(Twisted Pair)

26/82/300m
10GBASE-SR
(OM1/2/3)

CAMPUS
AND
DATA CENTRE

220m
10GBASE-LRM

300m
10GBASE-LX4

10Km
10GBASE-LR

40Km
10GBASE-ER

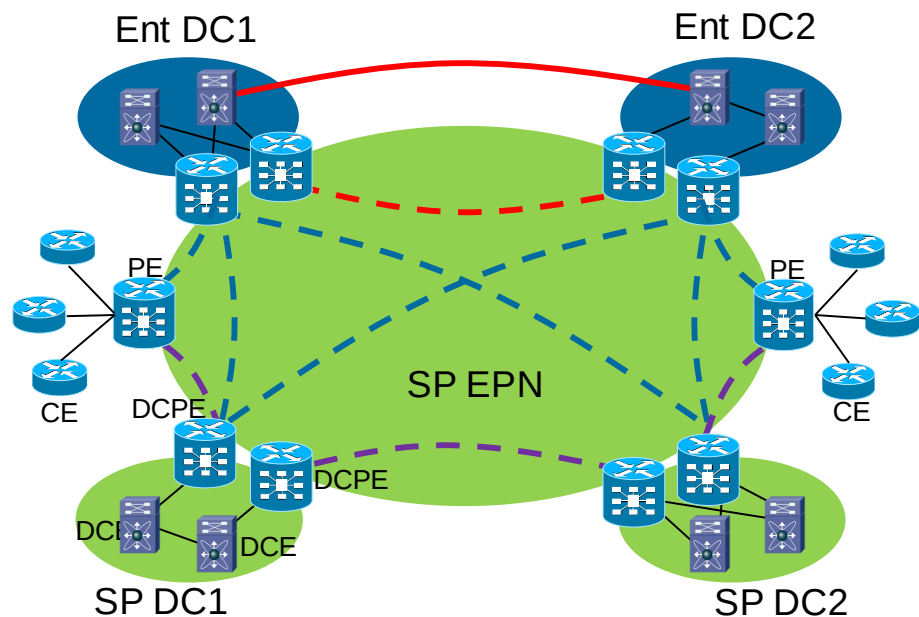
Cisco live!

A long-exposure photograph of a city street at night. The background shows tall buildings with lit windows and a pedestrian bridge. The foreground is dominated by vibrant, multi-colored light trails from moving vehicles, creating a sense of motion and energy.

40GE/100GE and Beyond Intra DC Consideration

Inter-DC Connectivity in the Cloud-era

More than DCI



- Enterprise Data Centre inter-connect
- Enterprise Data Centre to Provider Data Centre
- Provider Data Centre to Provider Data Centre

“DCI” with varying EGN requirements:

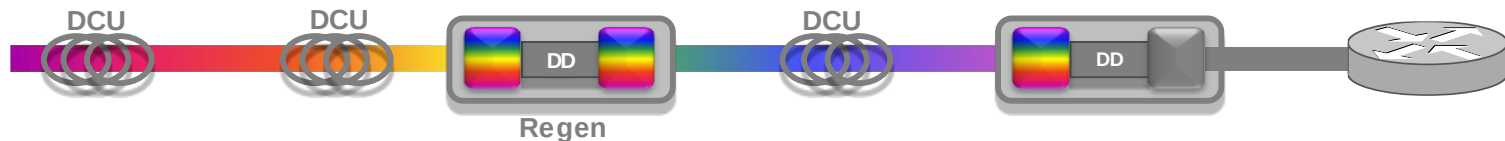
- Multiple 100G needs
- Higher Density Interconnect in metro
- Intra DC architecture extend beyond metro

100G Technology

Coherent Detection

Direct Detection

- Must correct for impairments in the physical domain (insert DCU's)
- Forced to live with non-correctable impairments via network design (limit distance, regenerate, adjust channel spacing)
- Dumb detection (OOK), no Digital Signal Processing, only FEC



Coherent Detection

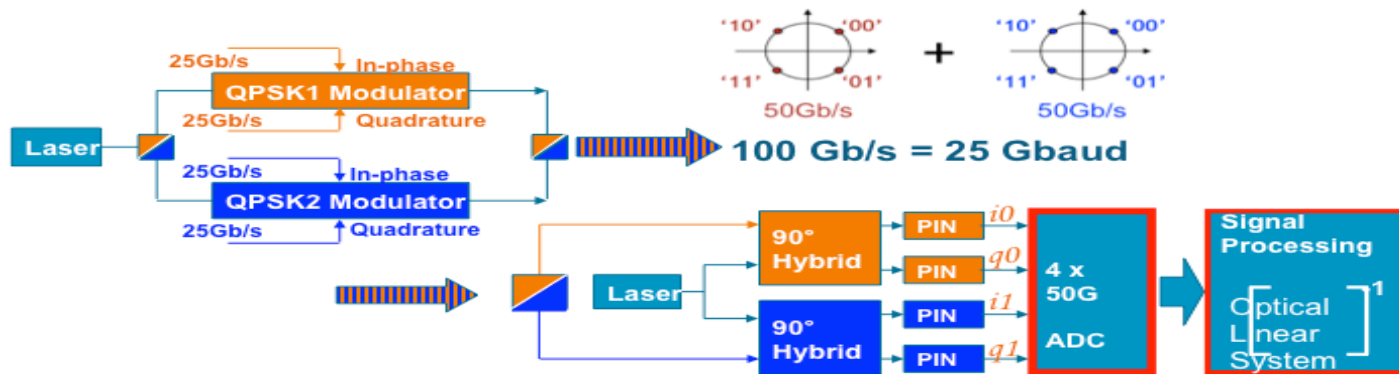
- Moves impairment correction from the optical domain into the digital domain
- Allows for digital correction of impairments (powerful DSP) vs. physical correction of impairments (DCU's). Adds advanced FEC.
- Massive performance improvements over Direct Detection.



100G DWDM Optics – CP-DQPSK

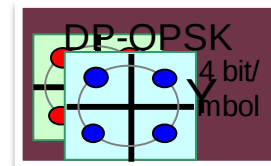
Coherent Detection and Post-Processing

100G PM-QPSK – At and / or exceeds 10Gig System Performance



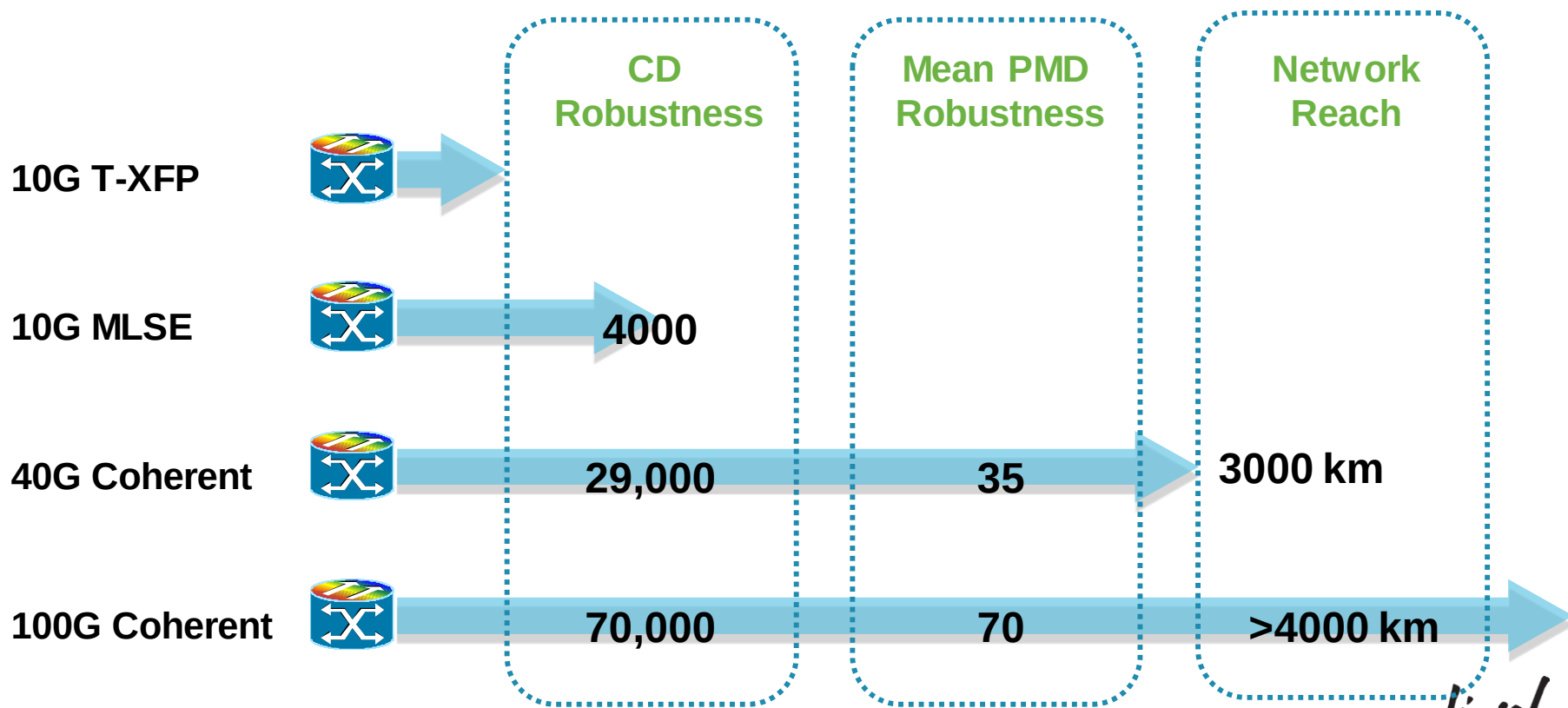
Four mutually orthogonal (“independent”) signals allow to recover the four bits transmitted in each symbol, if linear signal processing is applied

- RX Laser serves as Local Oscillator to provide a polarisation and phase reference
- Coherent receiver with Signal Processing:
 - Synchronises to carrier frequency and phase
 - Compensates CD and PMD
- Benfits: ~3dB better noise tolerance
~2x distance;
 - Can compensate for huge amount of Dispersion (>200x more than conventional)



100G Coherent

Dramatic Performance



High Speed Client Implementations

Interface Independent Functionality

- **IP-over-DWDM**

- Pre-FEC error threshold is monitored directly by router
- RP initiates fast re-route based on internal trigger directly from PLIM

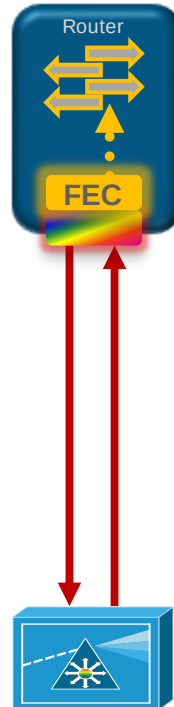
- **Gray Client - Ethernet**

- Pre-FEC error threshold is monitored by transponder
- Ethernet trigger is generated by transponder and sent to router which initiates fast re-route

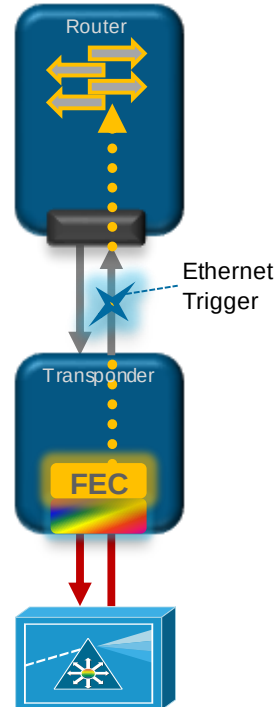
- **Gray Client - OTN**

- Pre-FEC error threshold is monitored by transponder
- OTN PF-FDI trigger is generated by transponder and sent to router which initiates fast re-route
- OTN interface monitors end-to-end path

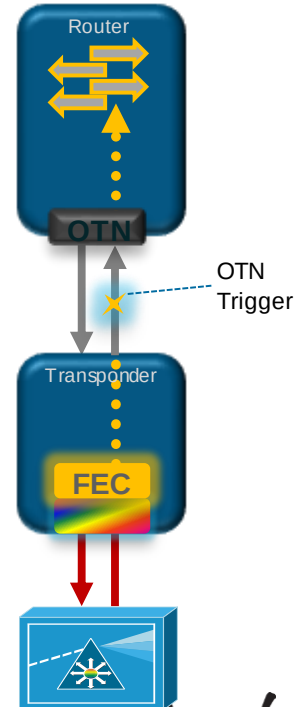
IP-over-DWDM



Ethernet Client



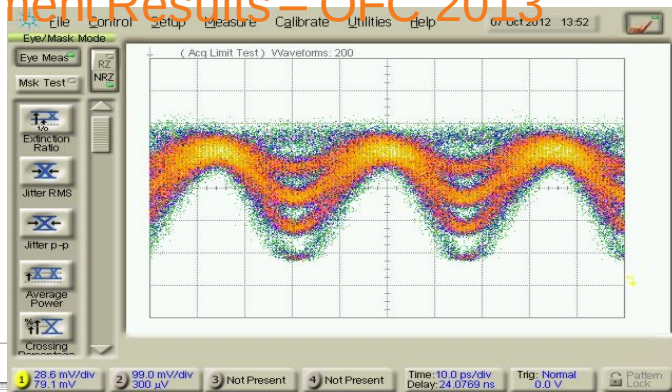
OTN Client



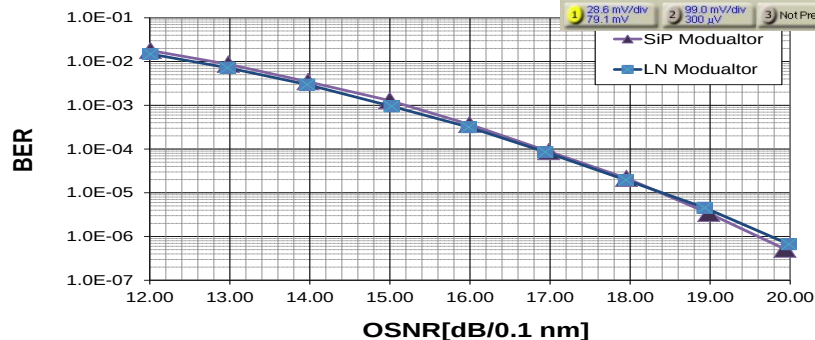
The WDM Promise of Silicon Photonics

100G DPQPSK Measurement Results – OFC 2013

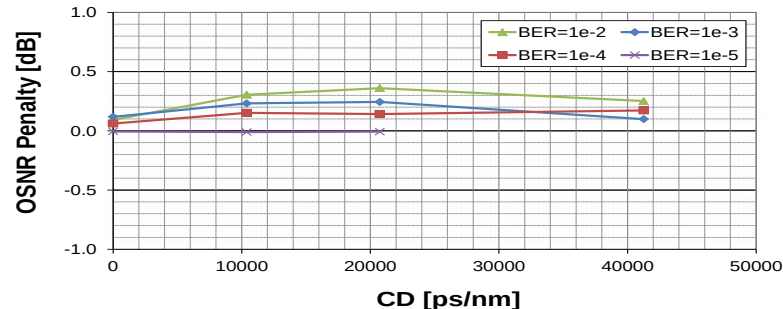
DP-QPSK Eye
Power Dissipation <1W
including drive circuits



Opportunistic evaluation.
Lot of room for improvement
with optimised ICs



B-t-B Measurements @ 100Gbps



OSNR Penalty of SiP wrt LiNbO3



Beyond 100G Client and Line Optics

Objectives for $\geq 100\text{Gb/s}$

- Cost reduction
- Increased system density
- OSNR performance improvement ($\geq 100\text{Gb/s}$)
- Spectral efficiency
 - reach optimised interfaces
 - capacity optimised interfaces
 - flexible wavelength assignment (flex spectrum)
 - optimised channel spacing
 - cross-talk compensation between channels

Line Interfaces – What's Next?

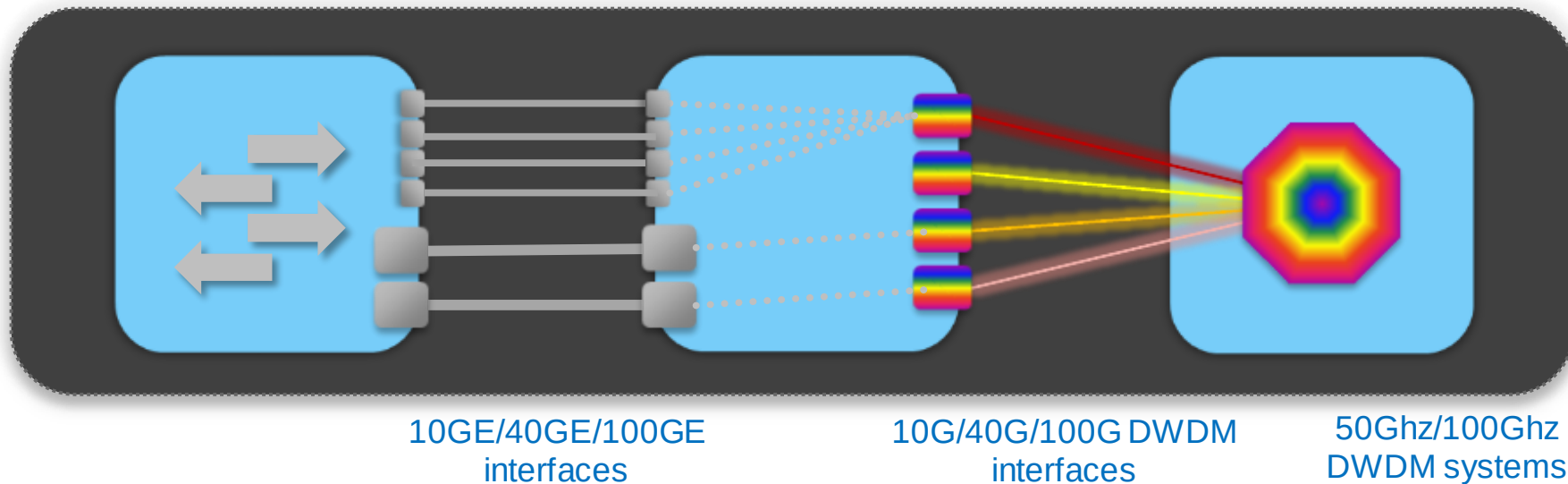
- Higher data rates
 - 200G, 400G, 1T
- Channel Flex
- Need to investigate other modulation techniques
 - PM-16QAM, PM-64QAM, or CO-OFDM
 - All come at the expense of reduced distance
- Need deeper look at FEC
 - Soft decision FEC
- Spectral Efficiency
 - Staying within the current fixed 50GHz grid is challenging !
 - Dynamic bandwidth filters (Flex spectrum ROAM technology)

Network Today

NPU

Transponder

DWDM



- Ethernet MAC/PCS layer fixed at 10G, 100G , 400G
- Modulation Scheme options limited to PM-QPSK (for 100G)
- Transponders tied to a single 100G PM-QPSK modulated output
- Fixed Grid DWDM systems allow 50Ghz OR 100Ghz channels

What is Channel Flex?

Flexible, efficient and dynamic mapping of packet services to optical transport

NPU

Transponder

DWDM

Superchannels

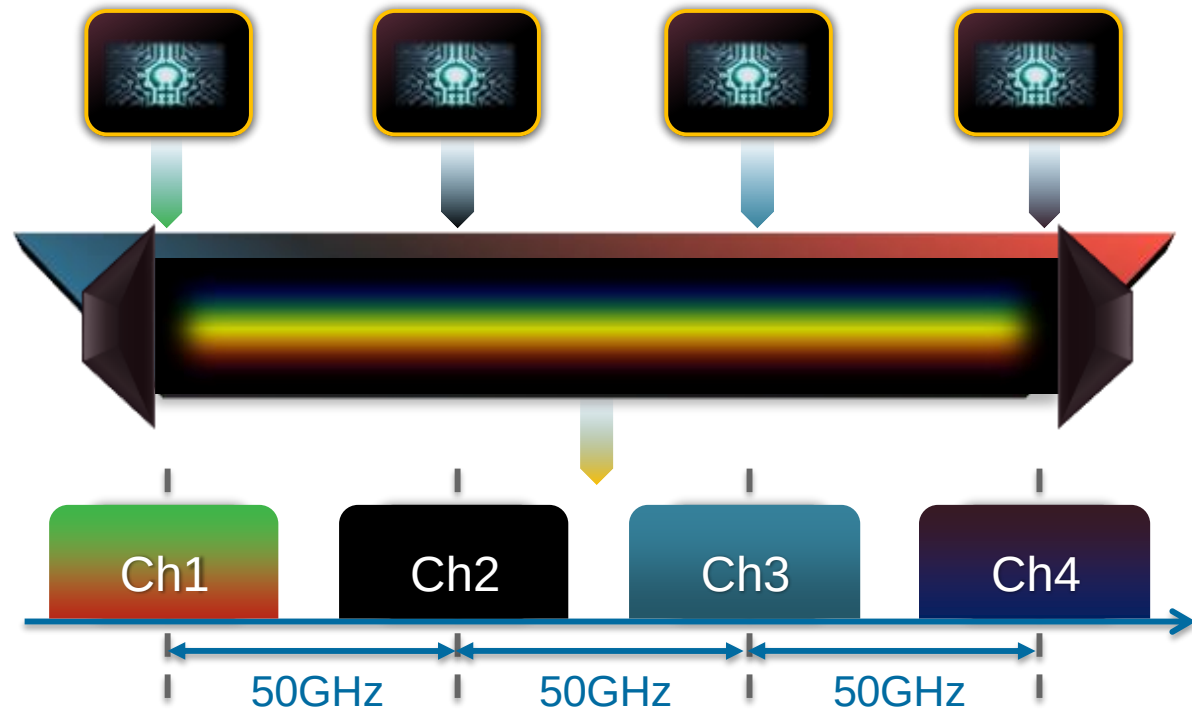
2x50G 2x200G

Flex MAC
Flexible nx5G/25G
interconnects

Flex Mod
50G/100G/200G DWDM
interfaces

Flex Spectrum DWDM Architecture

FlexSpectrum DWDM system
Today's 50GHz Grid System



DSP-Enabled
Transmitters

Flex Spectrum
ROADM

Signal Shaping

Denser Channel
Spacing

Flex Spectrum

The ability to combine arbitrary continuous slices of C-Band spectrum to form a larger channel.

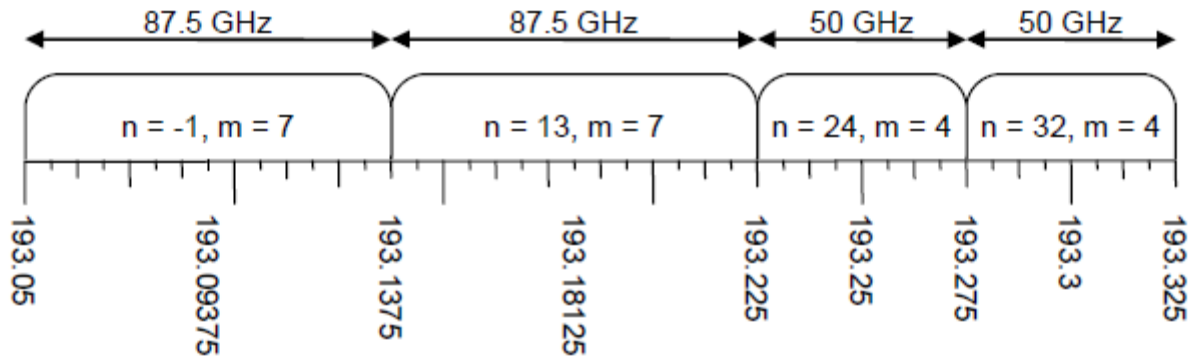
As per ITU-T G.694.1 flexible DWDM grid, Channels have a :

Nominal central frequency (in THz) defined by :

$193.1 + n \times 0.00625$ where n is a positive or negative integer including 0 and 0.00625 is the nominal central frequency granularity in THz

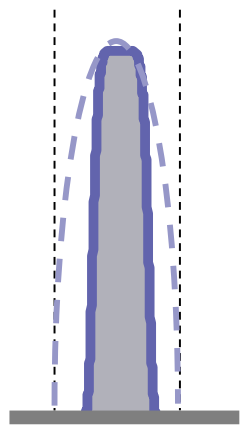
Slot width defined by:

$12.5 \times m$ where m is a positive integer and 12.5 is the slot width granularity in GHz.

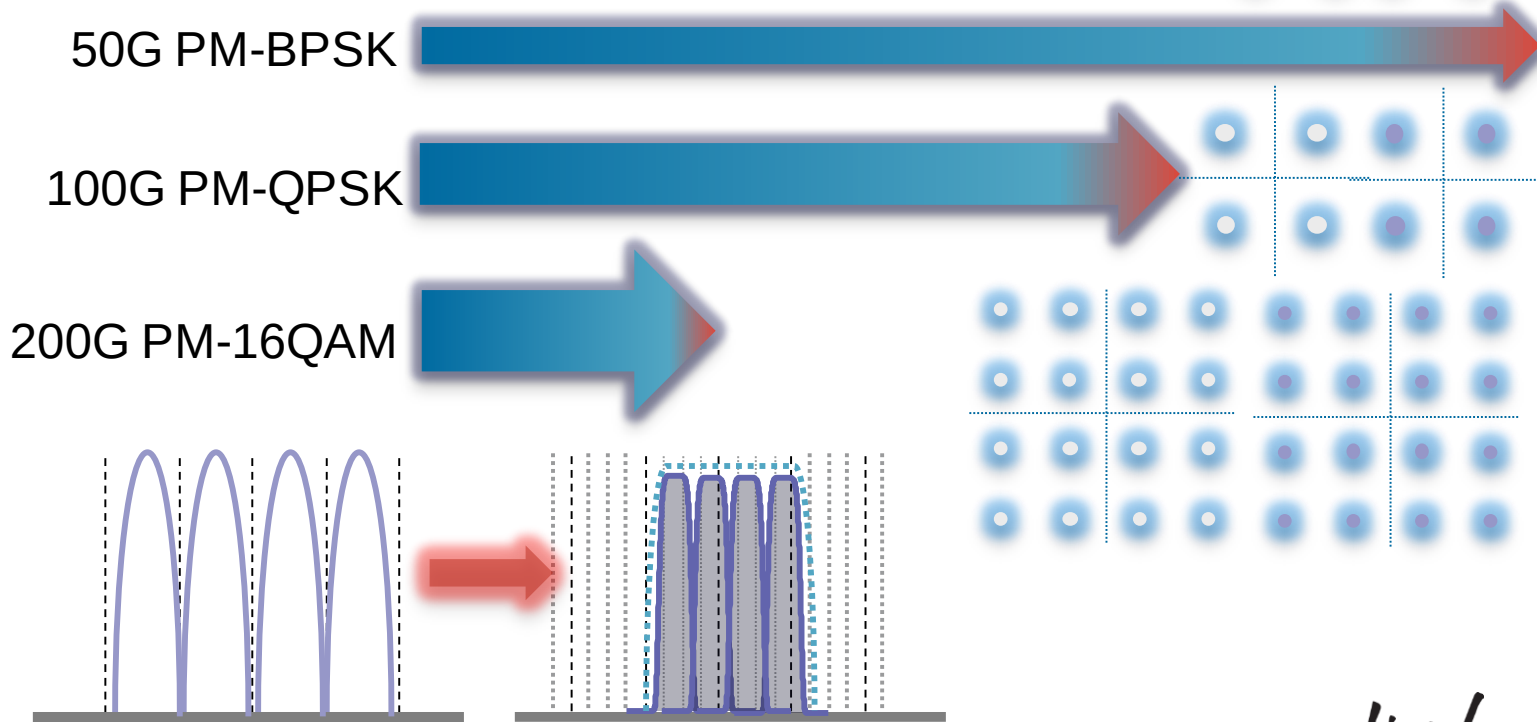


Flex Mod

Transponders supports Nyquist shaping and software configurable modulation

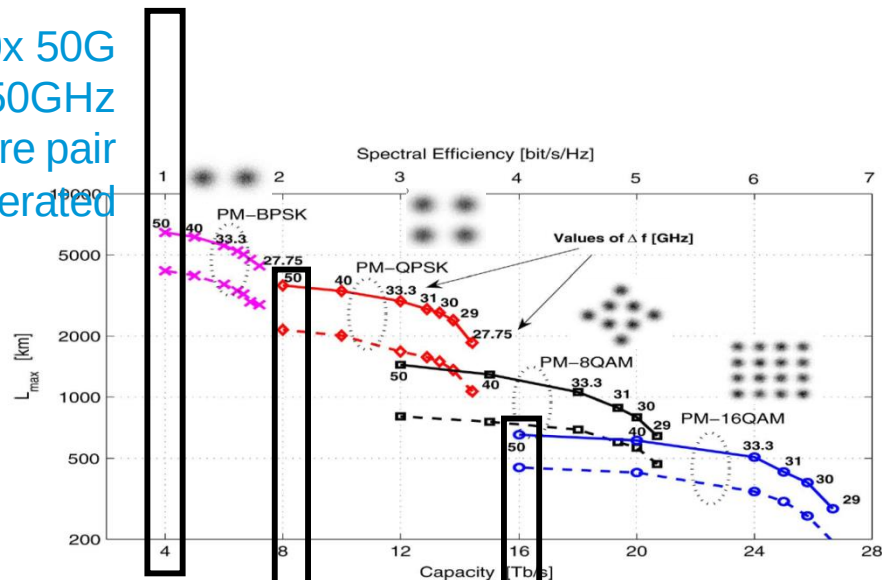


28 Gbaud/s
Nyquist shaped



Reach and Capacity Relationship

New DSP with 80-WXC: **80x 50G**
@ 50GHz
4Tb/s per fibre pair
Over 6,000Km Unregenerated

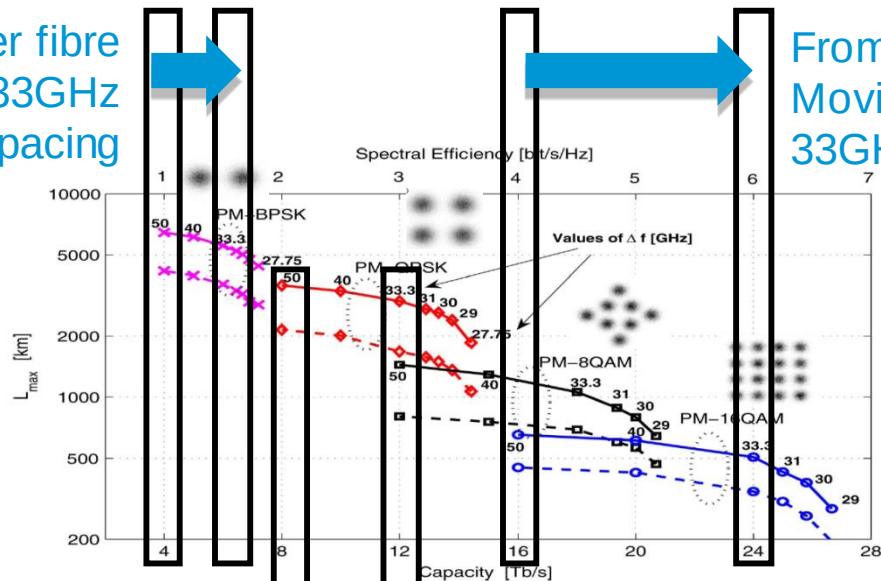


Today capabilities with 80-WXC:
80x 100G @ 50GHz
8Tb/s per fibre pair
Over 3,000Km Unregenerated

New DSP with 80-WXC: **80x**
200G @ 50GHz
16Tb/s per fibre pair
800 to 1,000Km Unregenerated

FlexSpectrum and Capacity Relationships

From **4Tb/s** to **6Tb/s** per fibre
Moving from 50GHz to 33GHz
Chs spacing

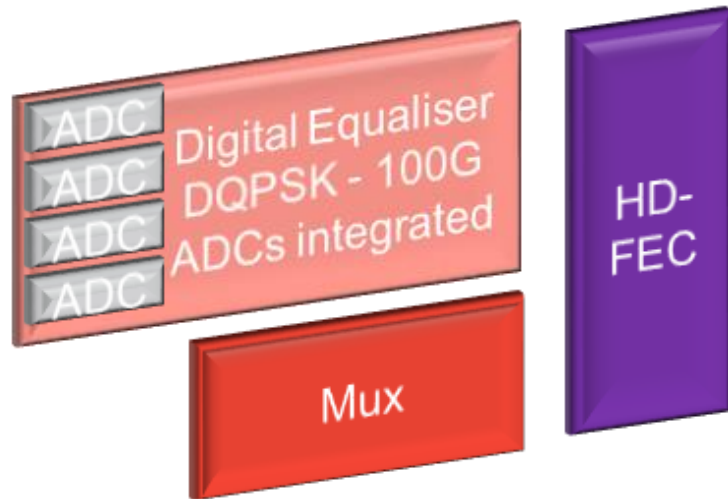


From **16Tb/s** to **24Tb/s** per fibre
Moving from 50GHz to 33GHz
Chs spacing

From **8Tb/s** to **12Tb/s** per fibre
Moving from 50GHz to 33GHz
Chs spacing

DSP Evolution

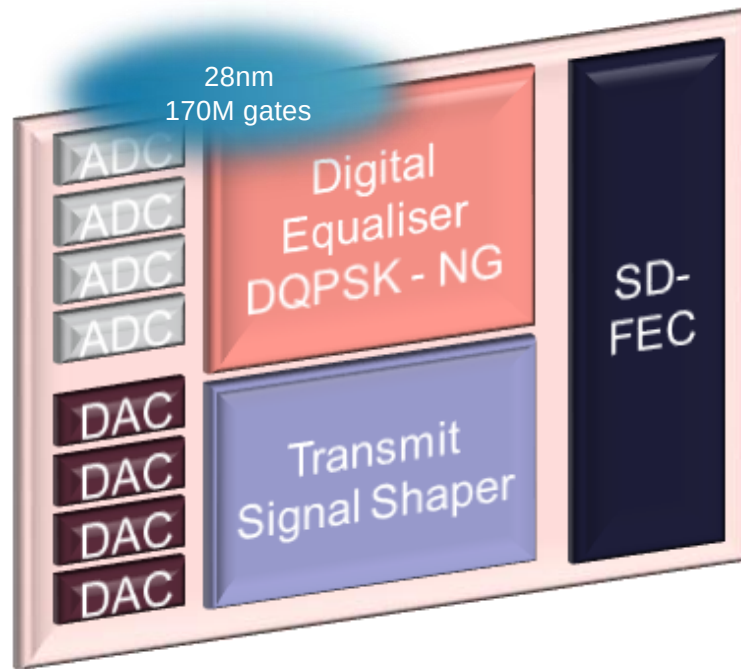
A Track Record of Silicon Innovation



100G

Receive side compensation

UFEC



50/100/200/250G

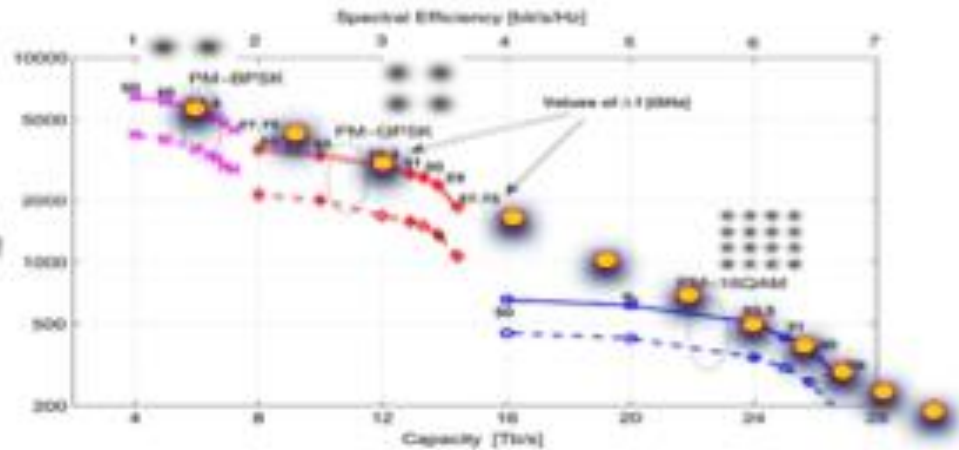
Receive side compensation

Transmit Signal Processing + DAC

2nd Generation SD-FEC

Next Generation Flex Mode: Filling The Gaps

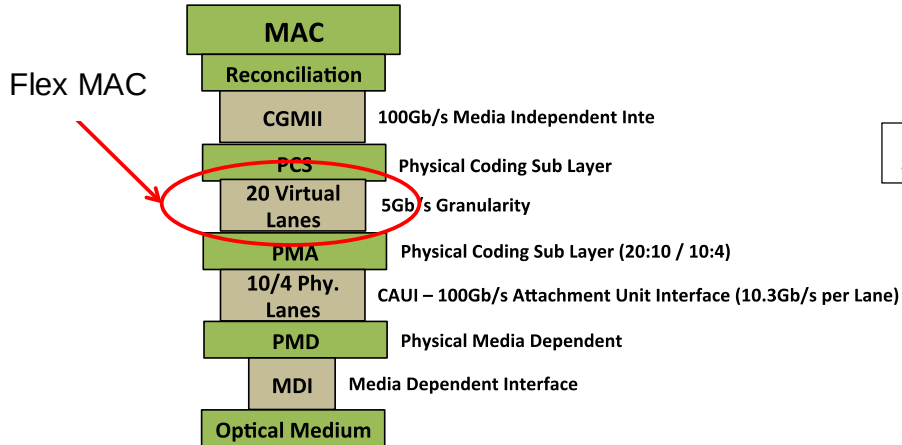
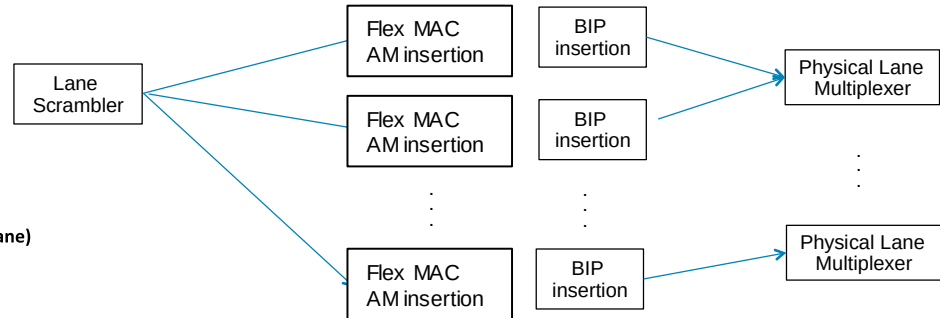
- 25G Granularity with different rates



Flex MAC

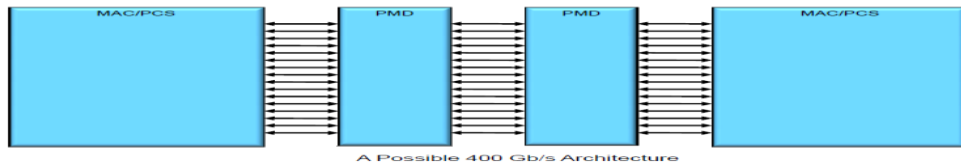
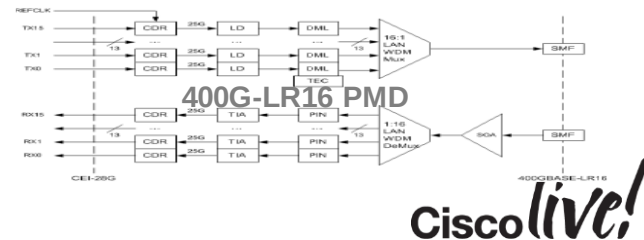
Flex MAC was designed to provide the following :

- Ability to adapt the data rate of the line interface to meet the available performance of the DWDM layer
- Allow for channel rate definitions outside the stringent hierarchies defined today in the ITU and IEEE without the need of LAG (Data Rate must be within capabilities of Network Processing Unit - NPU)
- Allow for hitless reconfiguration of Service channels



Client Interfaces – What's Next?

- High density low cost 100G – QSFP28 (FF)
- 100G single lane optics – (lower cost) (SiPH w/advance modulation)
- 400Gb/s
 - Challenge – cost points
- Continued investment in higher speed. Cant just go parrallell, hence advance modulation
- We need keep interfaces narrow (like 10G) to get lower cost
- Will have to follow patterns of LH for cost reasons with advanced mod





Summary

Agenda

- Trends / Introduction
- 40GE & 100GE Standards
- 40GE Transceivers and Cables
- 100GE Transceivers and Cables
- Impact of 40GE & 100GE on DC Fabric
- 40GE & 100GE and beyond Inter DC consideration
- Summary



Summary – Technology

- 40G is mainstream – cost points of 10G (40GE BiDi)
- High density 100G will become mainstream (industry focus)
 - QSFP28
 - Advanced modulation
 - SiPh
 - High 100G will be enabling for core and access
- 400G
 - FlecMAC
 - Advanced modulation
- Optimised system interconnects on the horizon
 - optical backplane, embedded, disaggregation of components etc..

Summary - Trends

- Transition infrastructure to duplex fibre for lower overall cost
- Balance choice of optics with cost, reach, power and packaging
- Move to high speed optics in the DC fabric improves application performance
- CMOS photonics enables enable new generation of SM optics (CPAK) and beyond
- Move to SM backbone in DC will require low cost short reach SM optics
- Evolution of high speed optics will enable flexible bandwidth, increased system performance, drive network architecture and facilities consideration
- Cisco continues to invest and lead the industry in optics innovation to drive to lower cost structure.

Deployment Consideration

Multimode OM3 duplex fibre for:

- <100m links, for 40G* and 100G
- No change from the current 10G fibre infrastructure

Multimode OM4+ duplex fibre** for:

- 100-150m links, for 40G and 100G

Single mode duplex fibre for:

- >150m links, for 40G and 100G

BiDi innovation enables dual fibre forward and backward compatibility for high speed interfaces on MMF

*125m supported

** New version of OM4 fibre for 150m



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