

Building the 400G Internet

Trends, Technologies and the Road to 800G+

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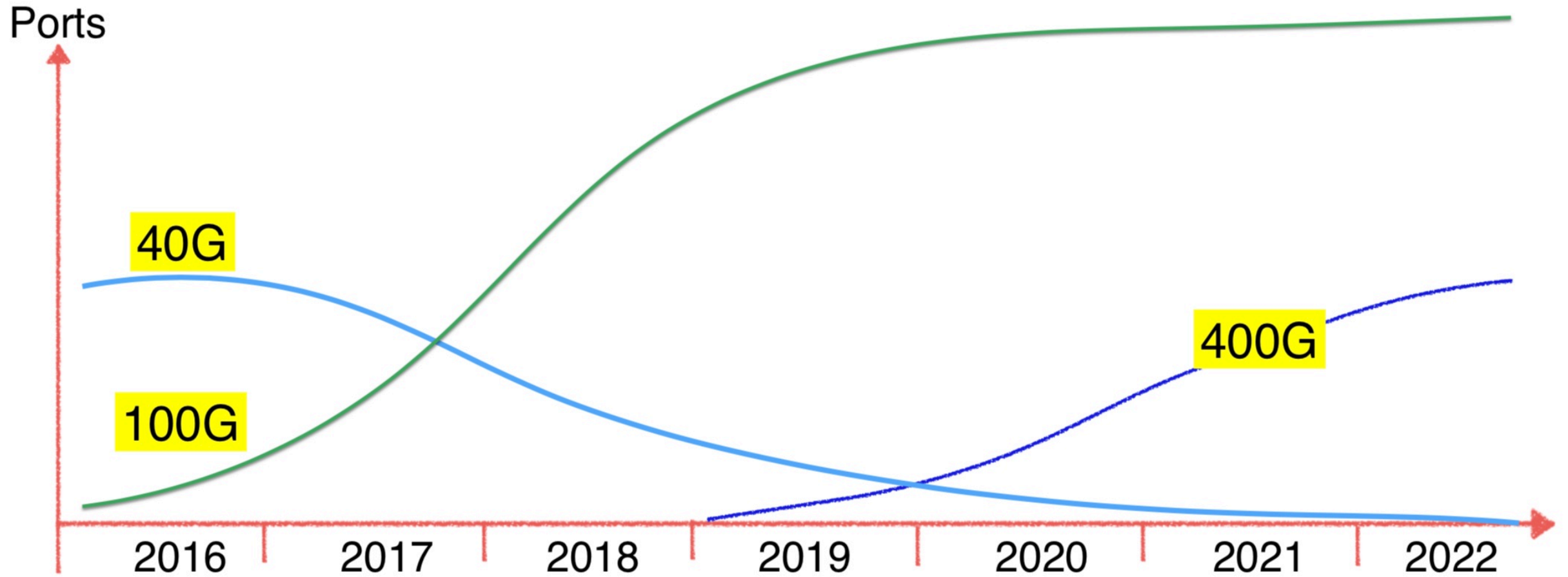
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The Easiest Way to Go Faster is to go Faster

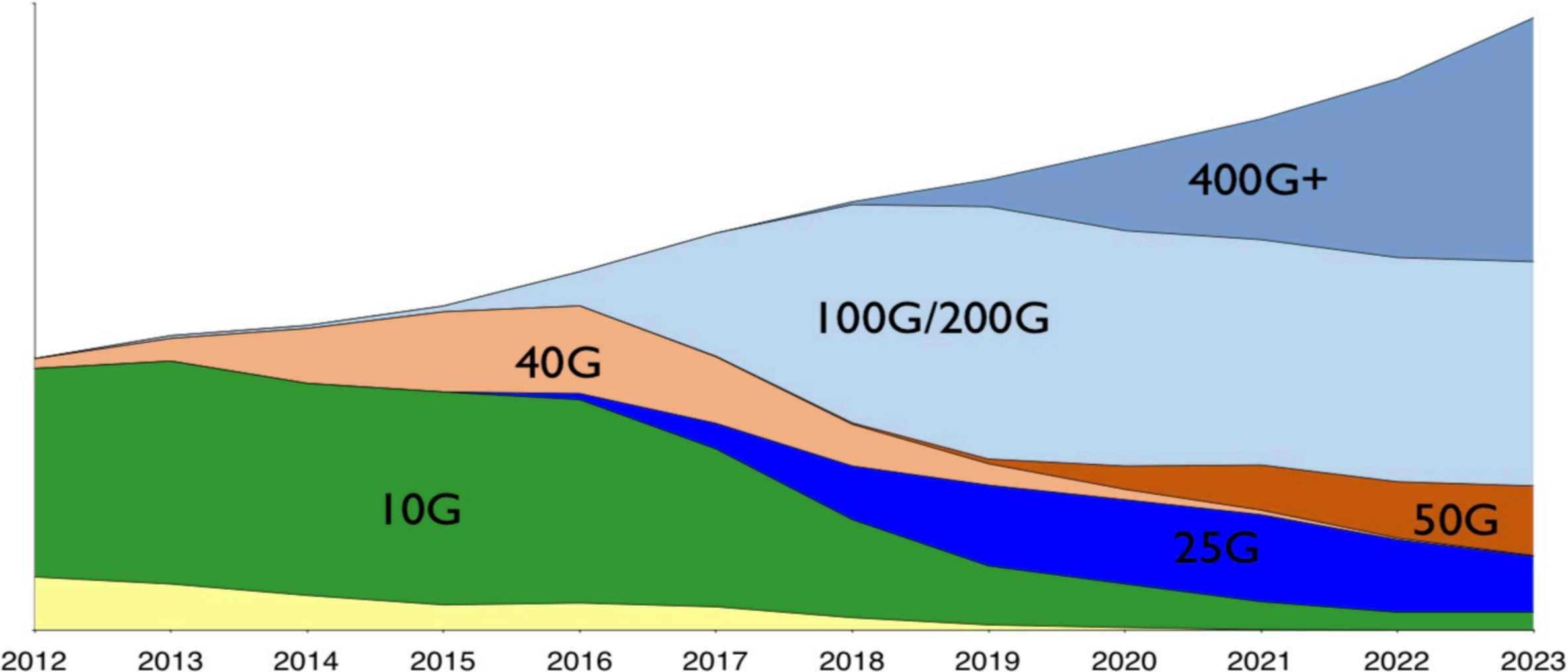
Ethernet Speed Transitions have been the primary driving force to improve the throughput and the price-performance of Service Provider and Data Center networks

40G - 100G - 400G Switch Port Transition

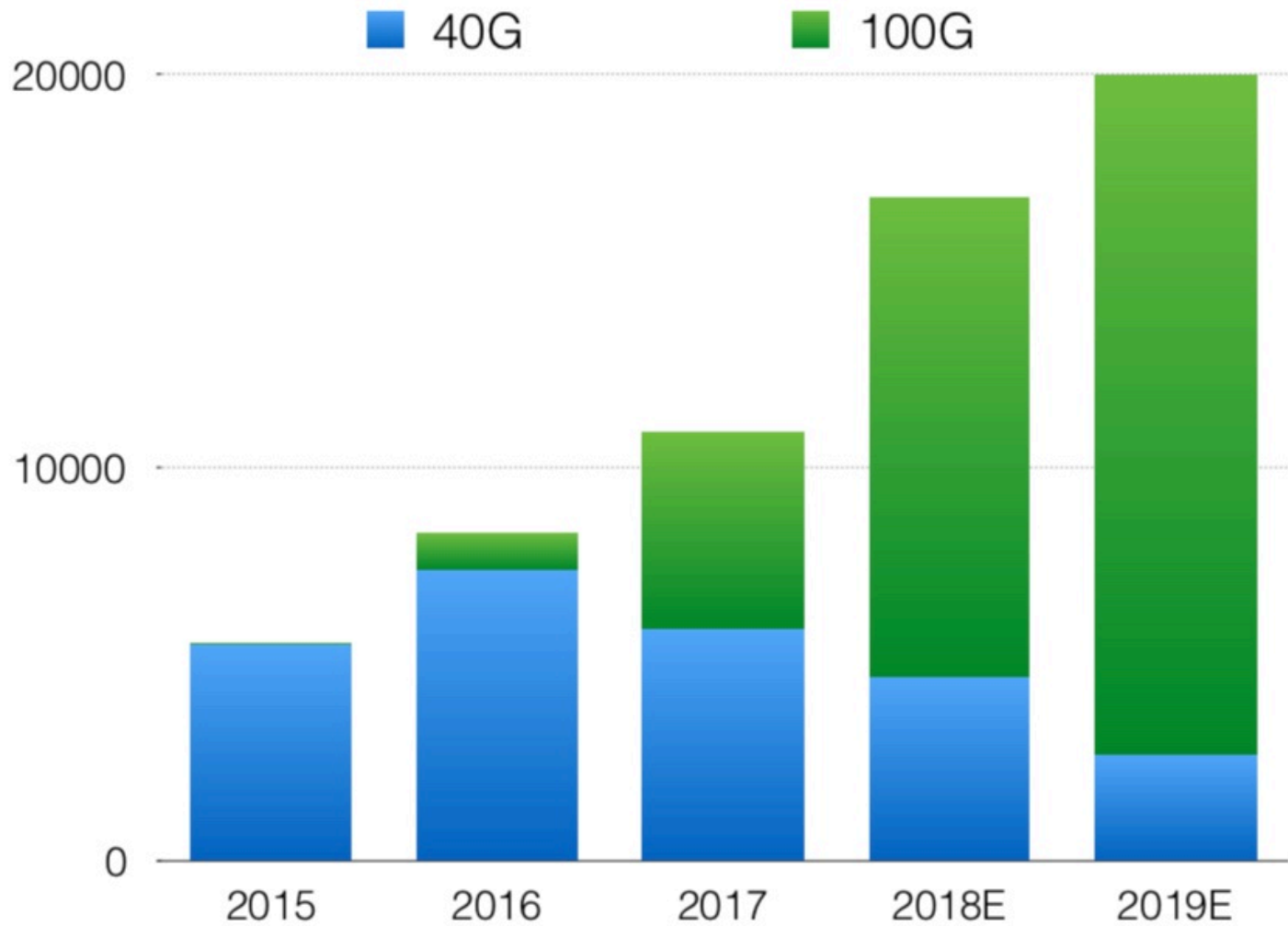


Source: Dell'Oro Group July 2018 Ethernet Switching Forecast

Ethernet Switch Revenue Forecast

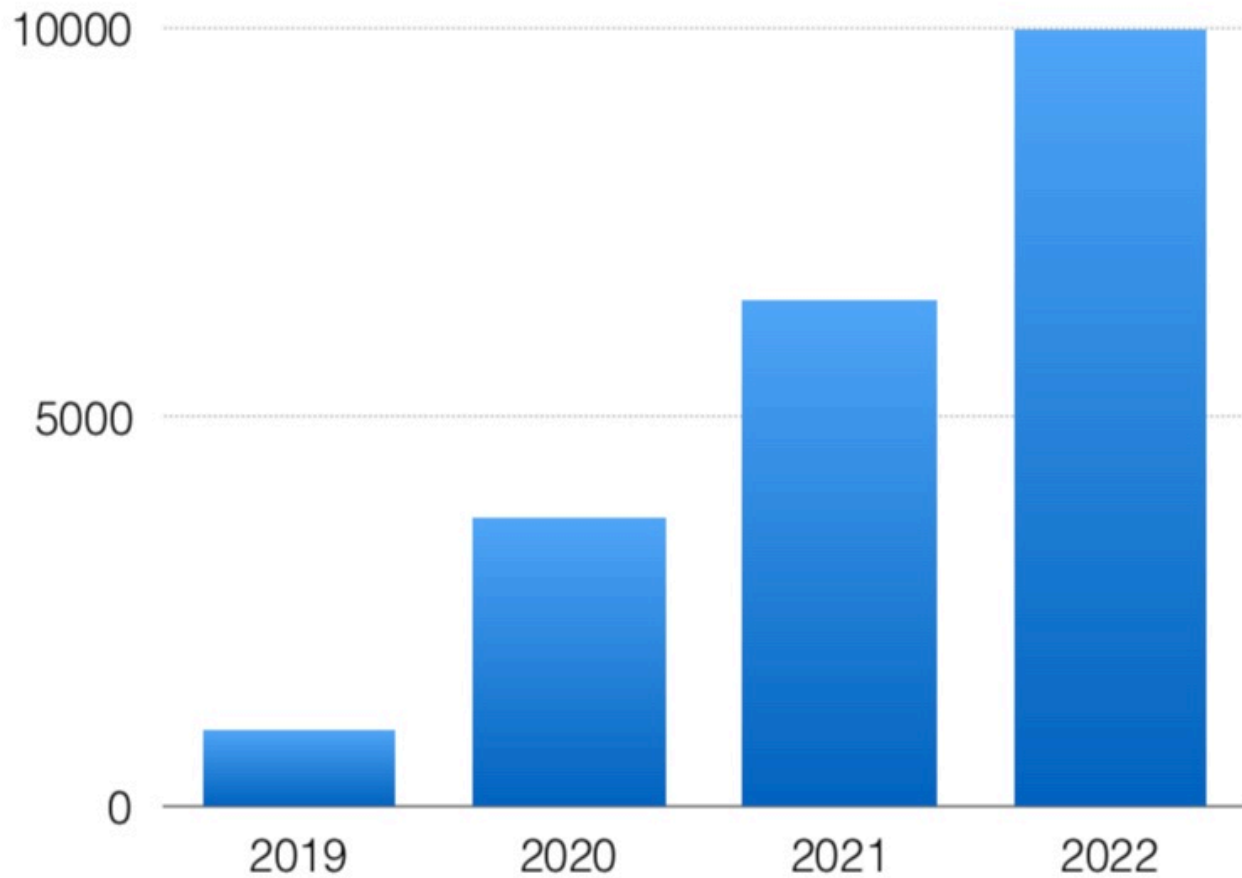


Source: Dell'Oro Group Jan 2018 Ethernet Switching Forecast



100G went from < 10%
to > 50% in one year

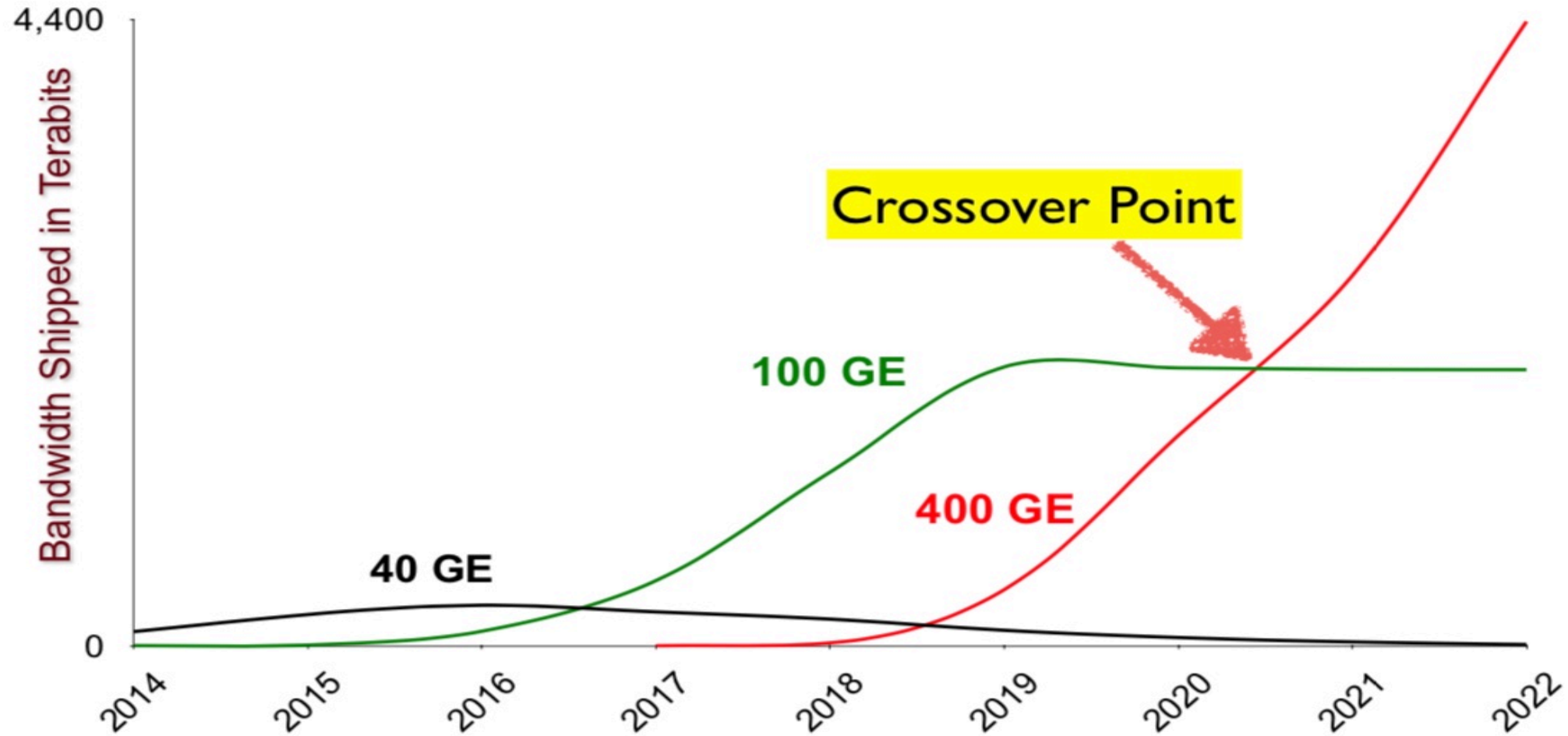
Source: Dell'Oro Market Research, Ethernet Switch Update, July 2018



Please note: market analysts count 400G switch port shipped irrespective of port configuration. A 400G port could be used in 1x400G, 2x200G, 4x100G or even in 8x50G configuration.

Source: Dell'Oro Market Research, Ethernet Switch Update, July 2018

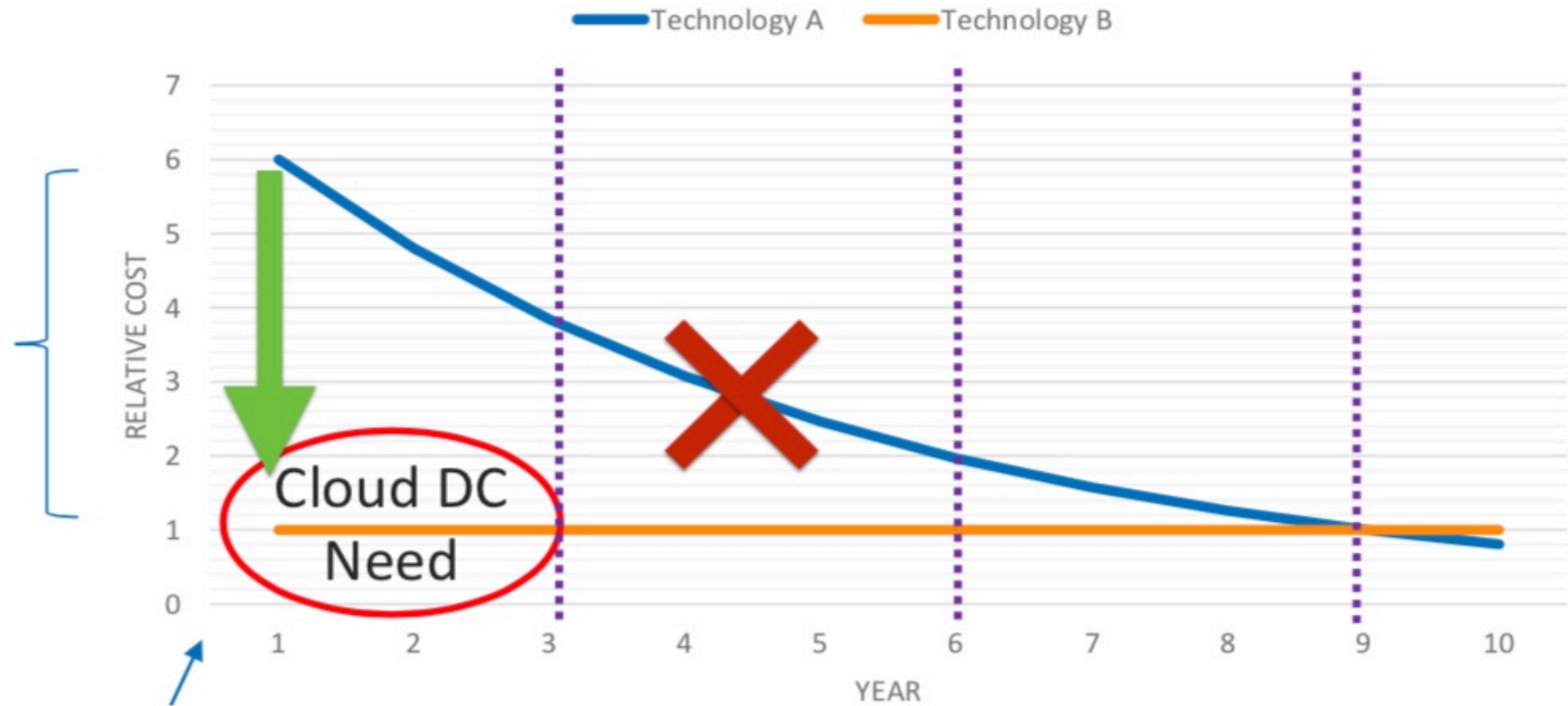
Expected 100G to 400G Bandwidth Cross-Over



Source: Dell'Oro Group July 2018 Ethernet Switching Forecast

The NEW Technology Learning Curve

Early high-volume (cloud) adopters not willing to pay premium for Technology A

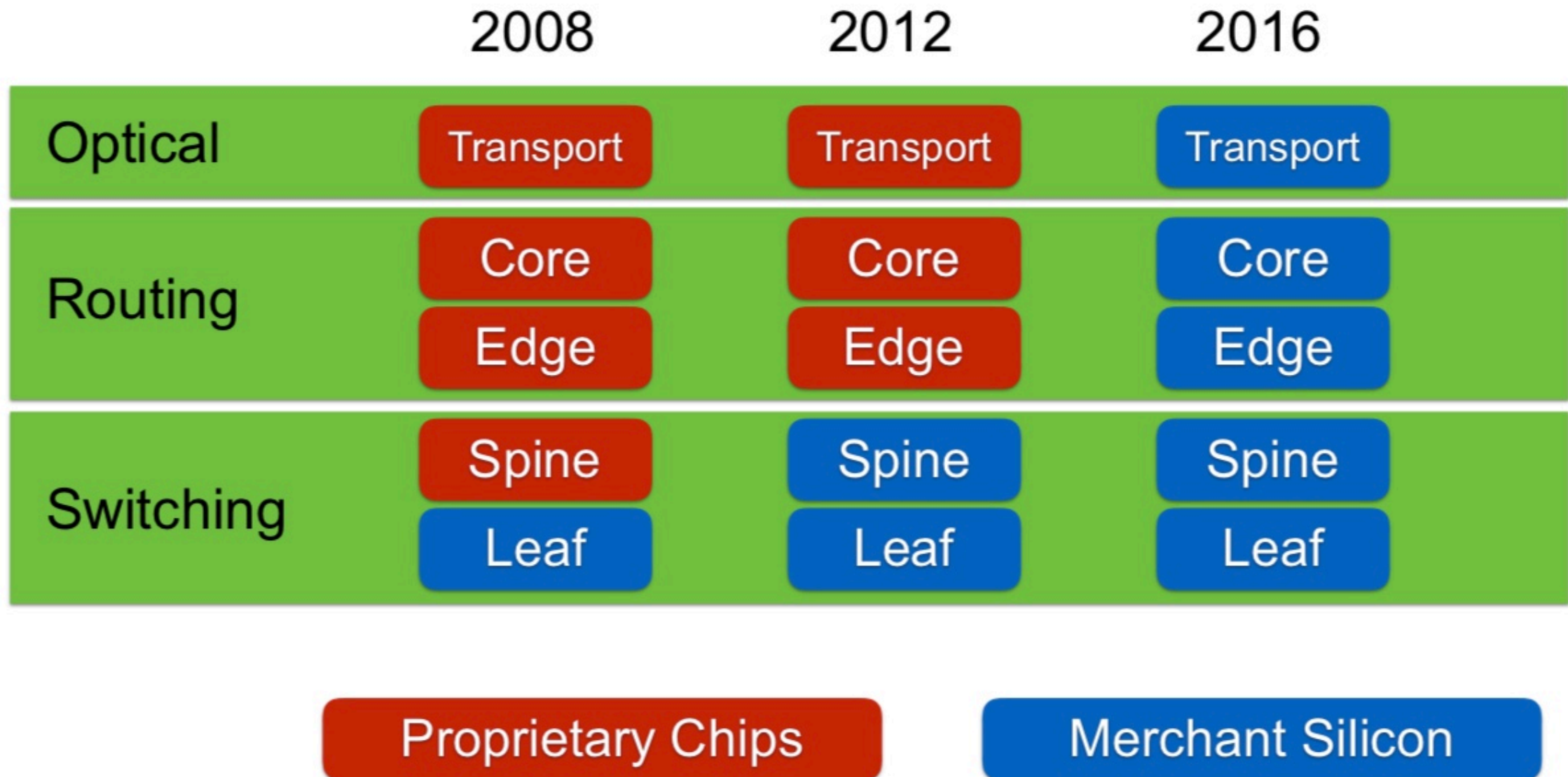


Source: Brad Booth and Tom Issenhuth Microsoft, IEEE 802.3 400G

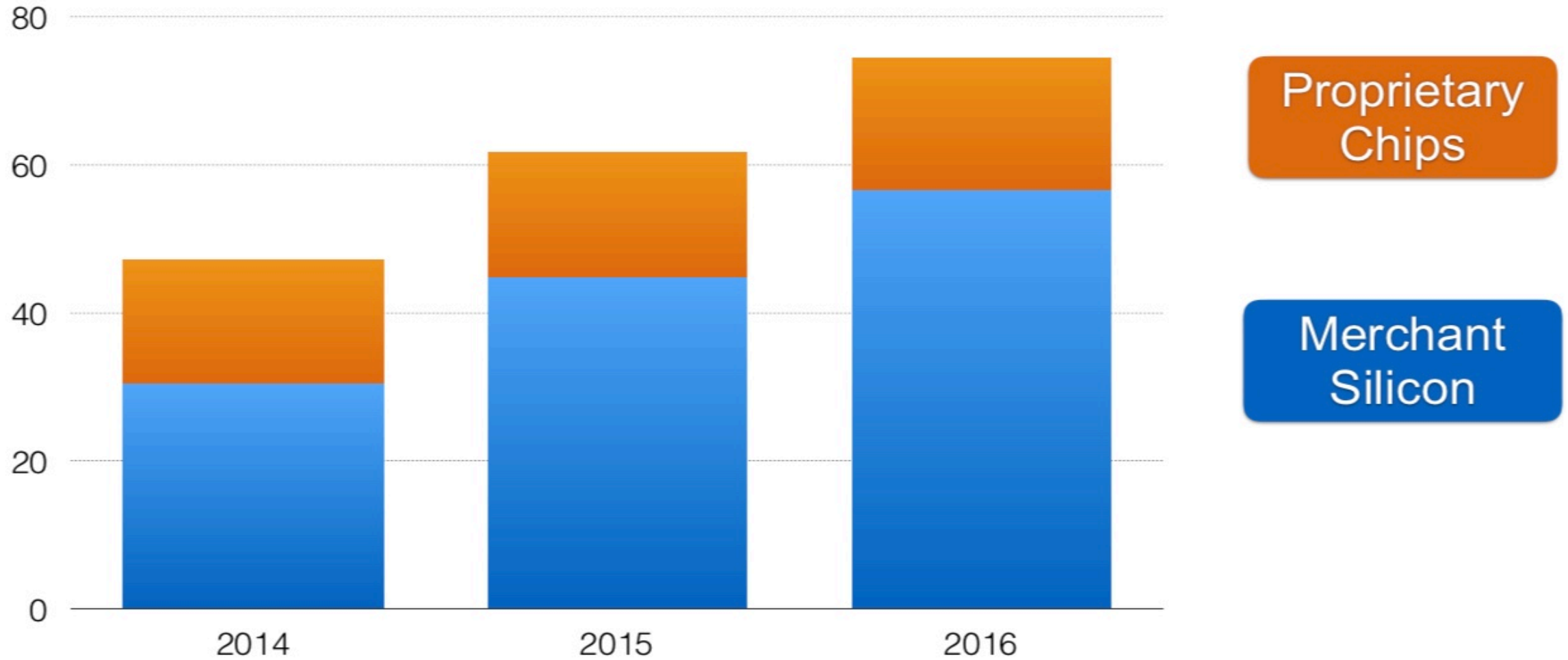
For a new technology to ramp quickly, it must be more cost-effective than the previous technology it displaces

Merchant Silicon Evolution

The Evolution of Merchant Silicon



Merchant Silicon Growth



Source: The 650 Group, Jan 2017

Single-Chip Switch Silicon Bandwidth Growth

[Gbps]

12800

9600

6400

3200

0

2008

2011

2013

2015

2017

2019

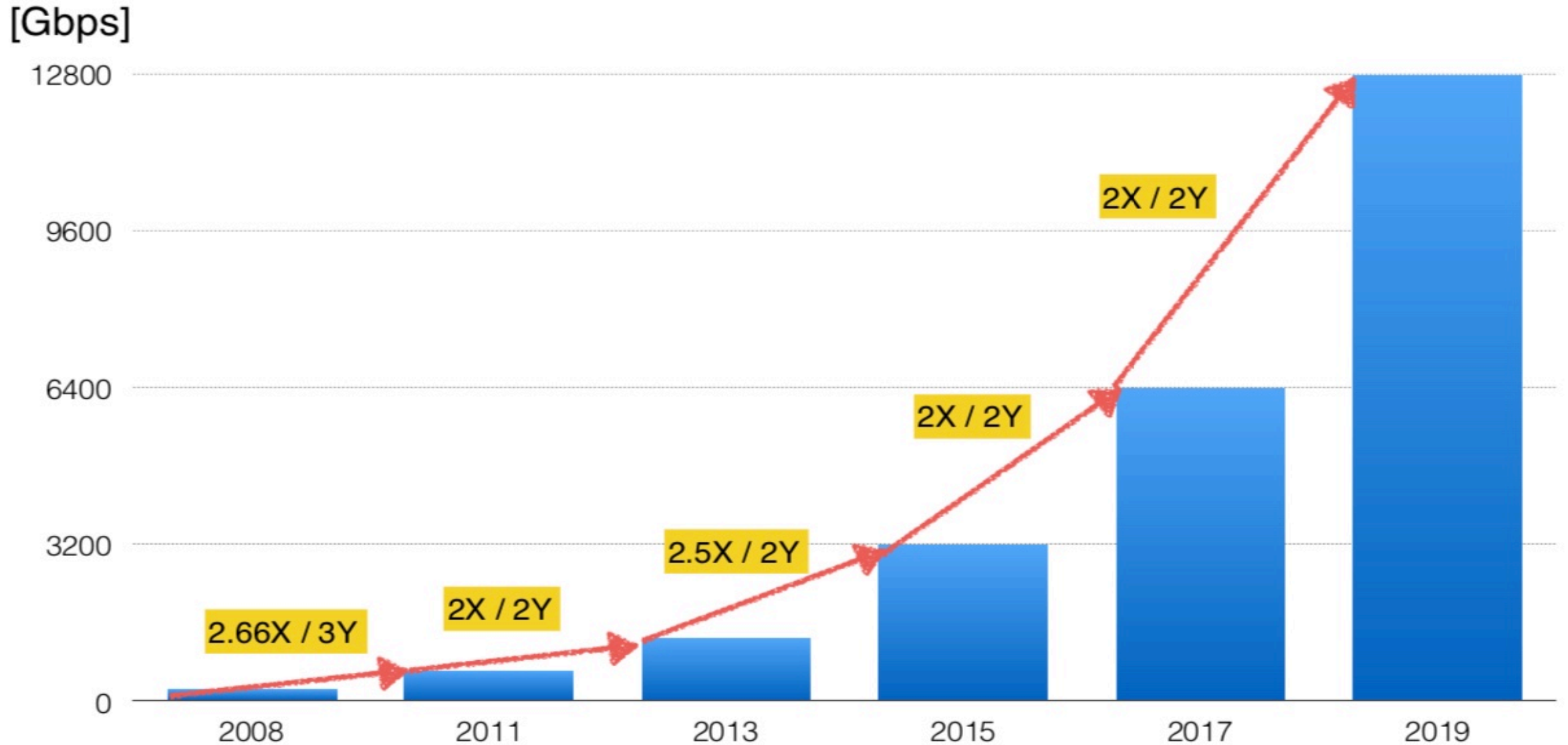
2.66X / 3Y

2X / 2Y

2.5X / 2Y

2X / 2Y

2X / 2Y



Semiconductor Process Technology Roadmap



Networking silicon technology has been lagging behind CPU/GPU
As a result, network silicon has more opportunity to improve further

Density Improvements Going Forward



28 nm die
1X

Shipping
Today



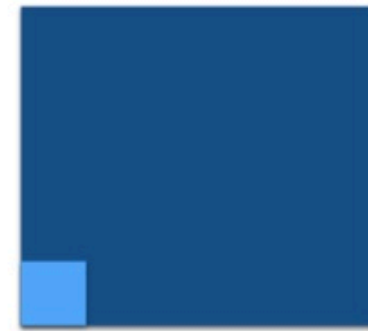
16 nm die
3X

2018-19
Silicon



7 nm die
15X

2020-21
Silicon



5 nm die
30X

2022-2023
Silicon

Each silicon generation enables more buffers, bigger routing tables

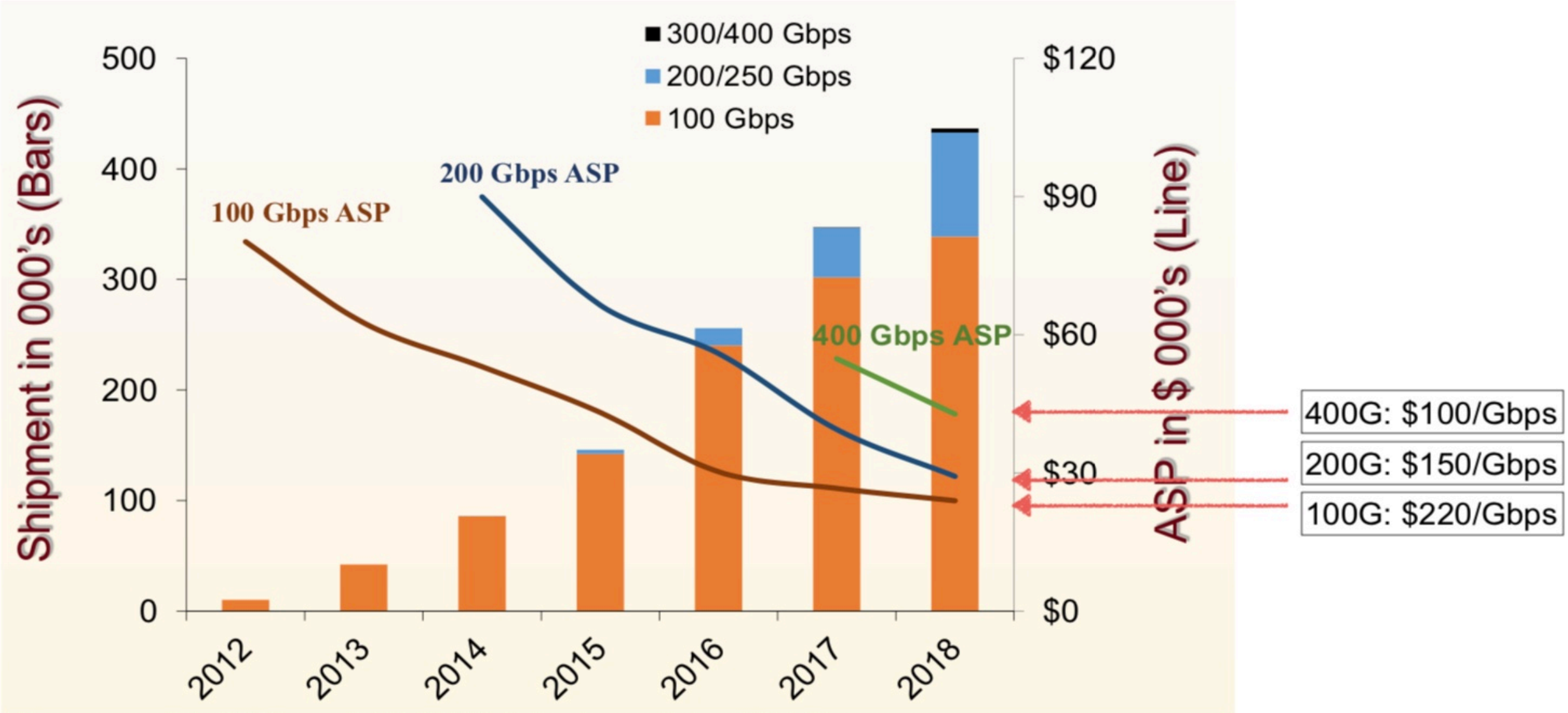
400G-ZR and 400G-ZR+ Digital Coherent Optics

What is 400G-ZR/ZR+?

- Industry's First Multi-vendor DWDM Standard
- Coherent, Tunable, Pluggable DCO Module
- 400G, 300G, 200G and 100G speeds
- Dense Client Optics Formfactor
- Supports 14.4 Tbps per 1U
- Max 20W power for 400G-ZR+

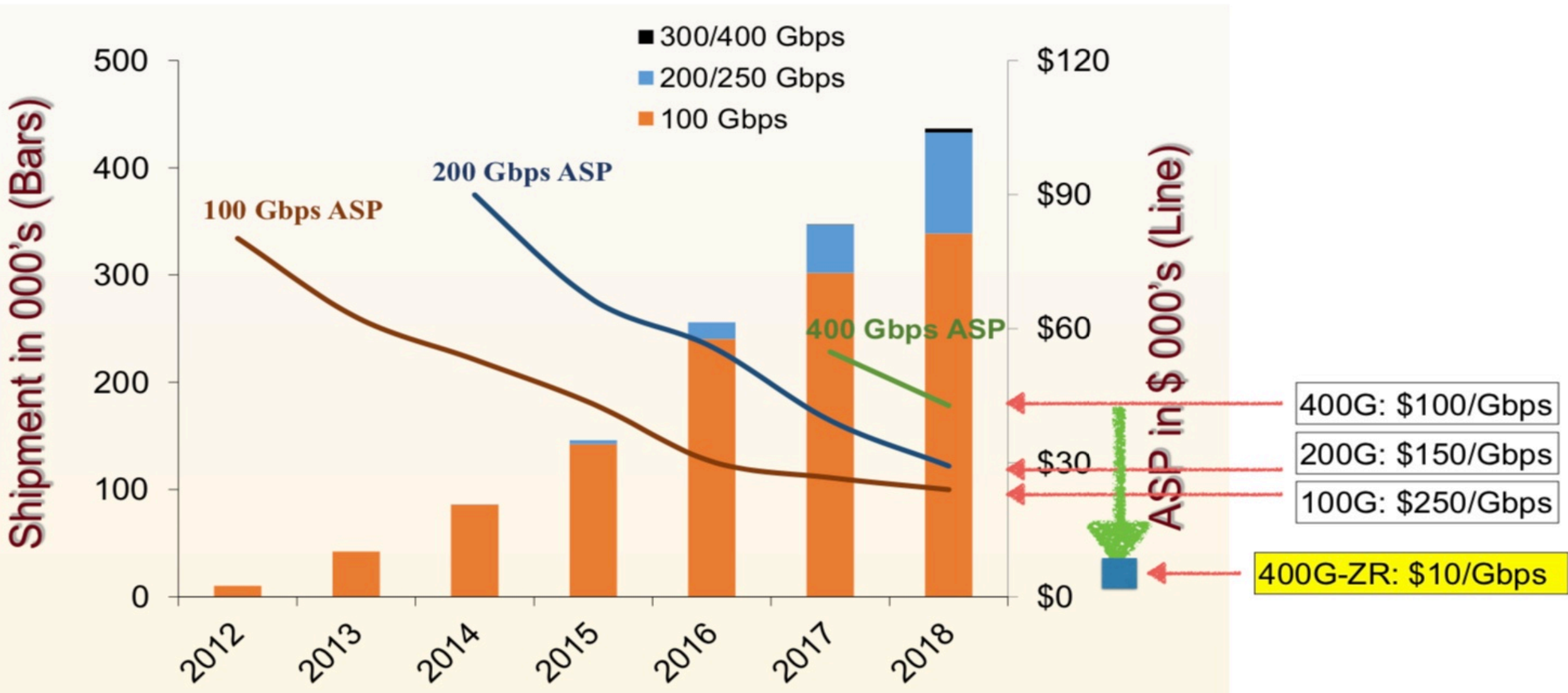


Current ASP (average sales price) of 100G, 200G and 400G DWDM Lines

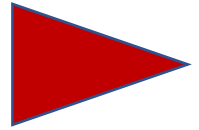


Source: Dell'Oro DWDM Update July 2018

Current ASP (average sales price) of 100G, 200G and 400G DWDM Lines



Source: Dell'Oro DWDM Update July 2018



Transformational Nature of 400G-ZR

- **Historically DWDM DSP Designs were Proprietary**
 - Vendor Lock-in is good for vendors, not customers
- **400G-ZR Implementation is standardized by OIF**
 - Multiple Competing Optics Module Vendors
- **Competition Changes the Pricing Environment**
 - Expect \$10/Gbps per 400G-ZR Module in Volume

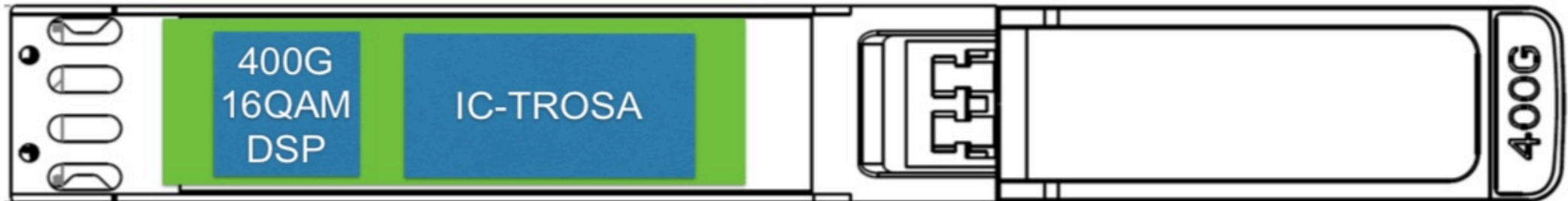
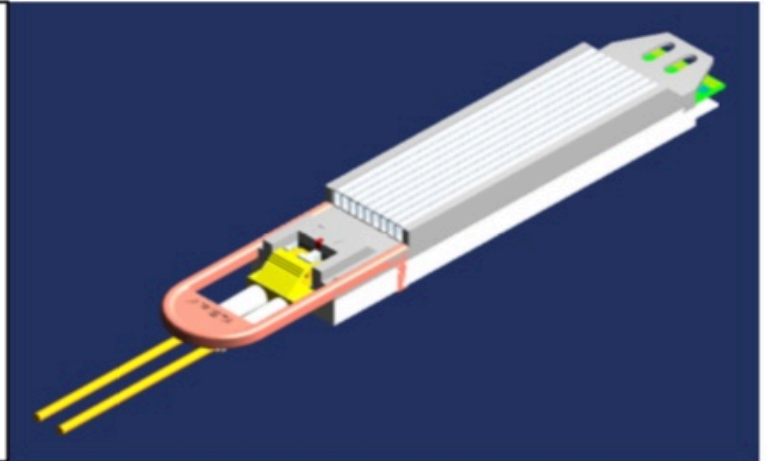
400G-ZR+: Up to 1000km Reach

400G-16QAM DSP + Coherent Laser

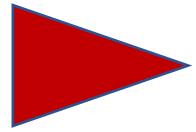
Up to 52 Terabits per dark Fiber (C+L Band)

400G-ZR: Up to 100 km Reach, 15W power

400G-ZR+: Up to 1000 km Reach, 20W power



Metro and Long Reach Coherent at same port density as Datacenter Optics



Inside the 400G-ZR/ZR+ DSP Chip

Client Interface
400/200/100G

FEC
Block

DSP
Block

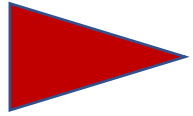
Dispersion
Compensation

400G-ZR Standard supports 100km Reach

400G-ZR+ with enhanced FEC increases reach up to 1000km

Performance approaching high-end / high power DSPs

Same DSP supports 200G-8QAM and 100G-QPSK



Why Pluggable Form Factor?

- **Customers can Source 400G-ZR Modules Directly**
 - Avoids Margin Stacking
- **System Vendor Can Build One System Design**
 - No Extra Investment Required to Deliver DCO
- **Customers Can Mix and Match DCO and Client Optics**
 - Easy Configurability and easy field replacement
- **Multiple SKUs Expected**
 - 10km-100km-300k—1000km, high output-power, etc

400G-ZR+ Covers all of Europe with 400G-DWDM

PAN EUROPEAN FIBEROPTIC NETWORK ROUTES PLANNED OR IN PLACE

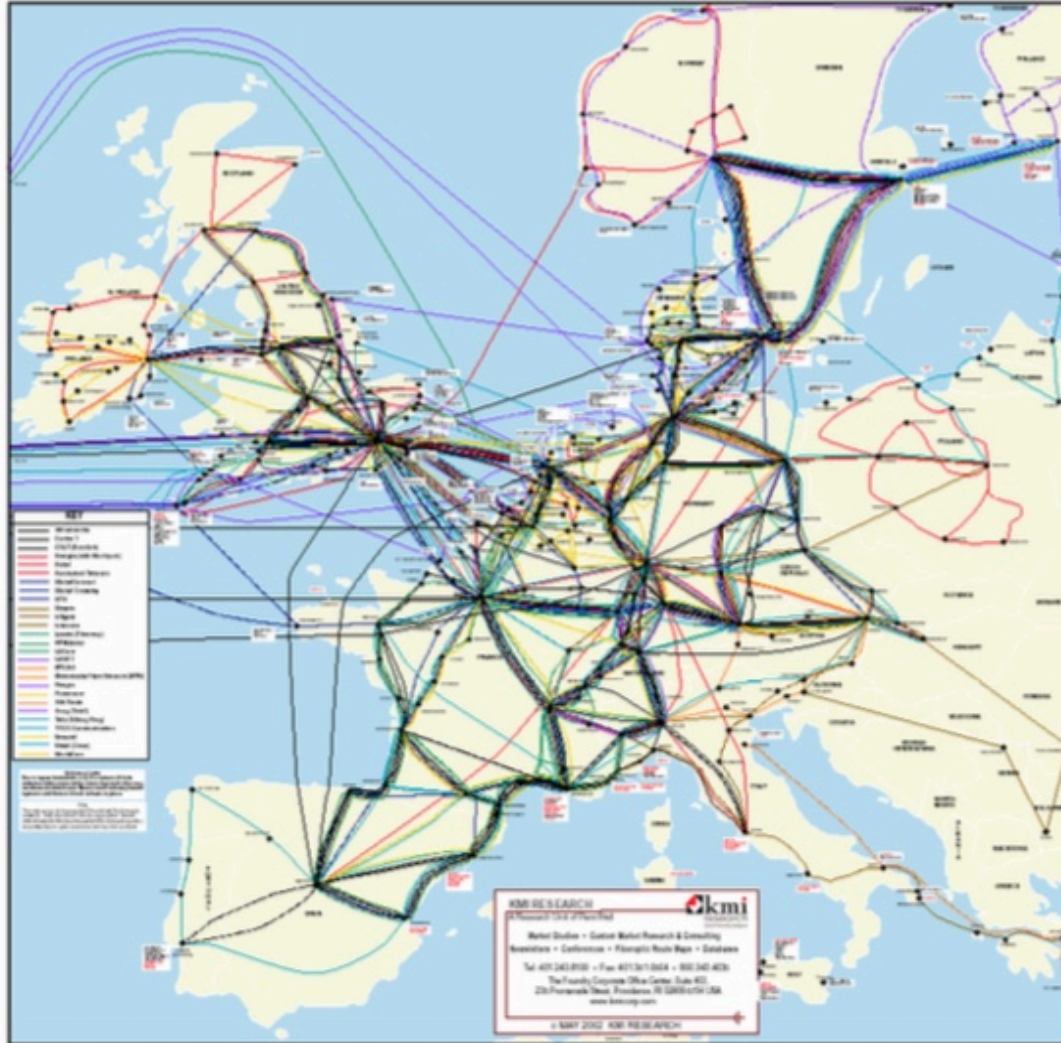


Image Credit: Mattia Cantono, Roberto Gaudino, Vittorio Curri, Stephan Pachnicke, "Potentialities and Criticalities of Flexible-Rate Transponders in DWDM Networks: A Statistical Approach," J. Opt. Commun. Netw. 8, A76-A85 (2016);

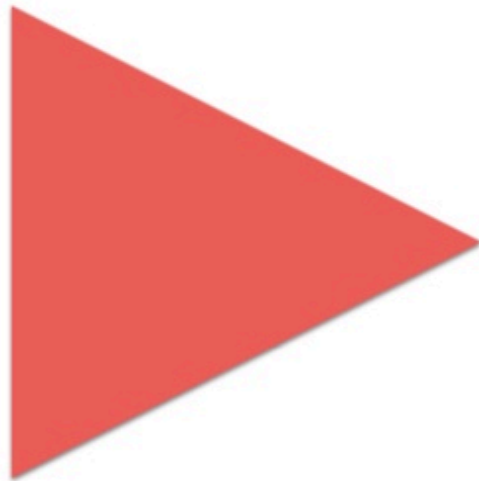
Pluggable DCO Form Factor Transition to OSFP



200G-16QAM 1000km
8 per 1U (1.6T)



100G-2PAM56 100km
36 per 1U (3.6T)

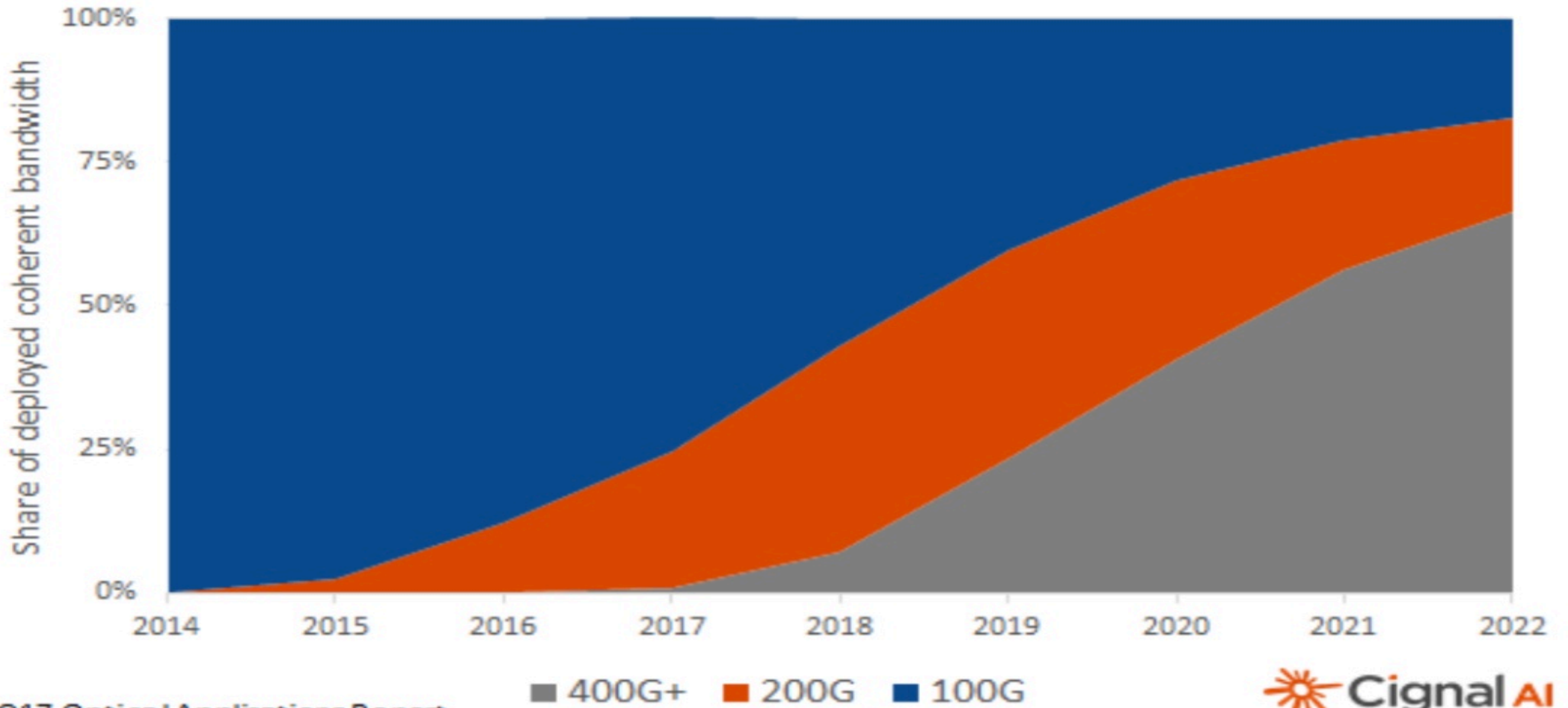


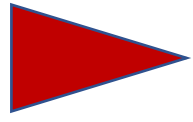
OSFP



400G-16QAM 1000km
36 per 1U (14.4T)

Coherent Bandwidth by Speed





400G-ZR DSP Summary

1. 400G-ZR is the first multi-vendor DCO Standard
2. Revolutionary Price-Performance, Density and Power
3. No need for separate transport shelves or platforms
4. Eliminates Special System Designs for DCO
5. IP/L3 becomes the Management Platform
6. Economics Drive Rapid Adoption of 400G
7. Roadmap to 800G-ZR (100km reach) in 7nm

400G and 800G Optics Module Form Factors

Thermal Requirement for 400G-ZR+: 20W

400G-ZR
100km Reach
15W Power

400G-ZR+
Up to 1000km Reach
20W Power

400G-ZR+ Optics Approaching the Performance of Traditional High-end DWDM Optics



Thermal Requirement 800G Optics: 20W

**400G-FR4/LR4 Optics
10-12W Thermal
Envelope**

**Dual 400G/800G Optics
Need 20W Thermal
Envelope**

No Significant Power Reduction going from 400G to 800G

Pluggable Form Factors Comparison



36 Port Density per 1U



20W Thermal Capacity for 400G-ZR+ and 800G



High Signal Integrity for 112G-PAM4 SerDes



OSFP is the right good choice for ZR+ and 800G (Dual 400G)

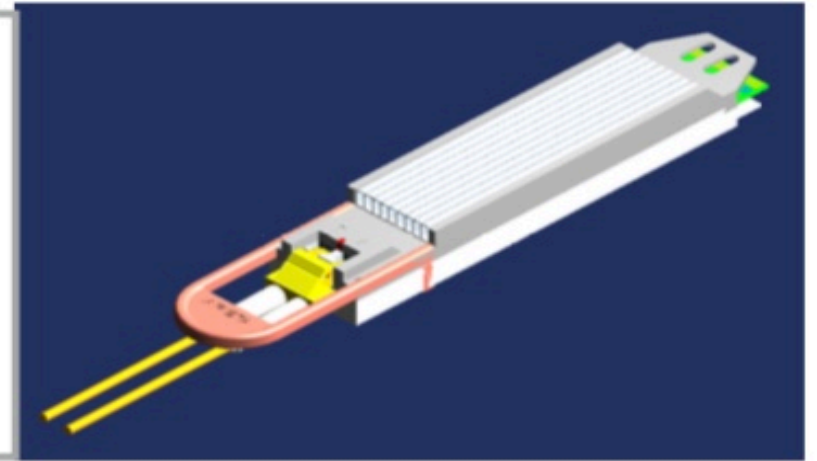
400G-FR4/LR4 OSFP Module

400G-FR4/LR4

8x56G-PAM4 Electrical Interface

Duplex LC Fiber Connector

Estimated Power: 12W



400G over Duplex Fiber

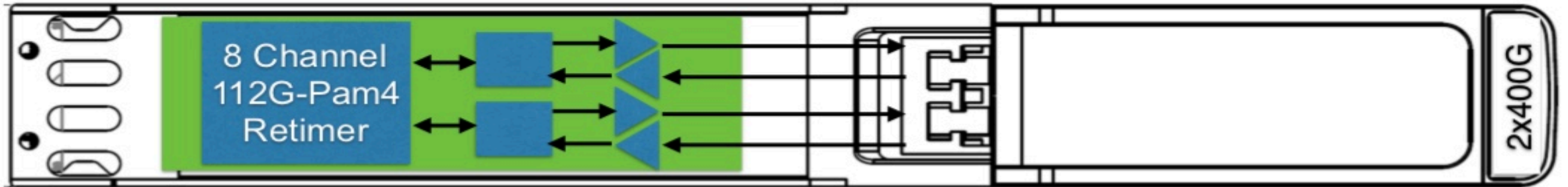
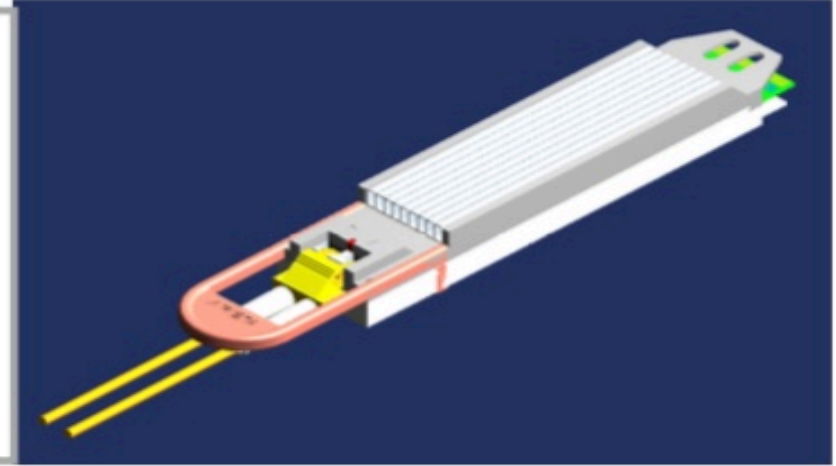
Dual 400G-FR4 OSFP Module

Dual 400G-FR4 in one OSFP Module

8x112G-PAM4 Electrical Interface

Dual CS Duplex Fiber Connector

Estimated Power: 20W



Dual 400G Optics over two fiber pairs

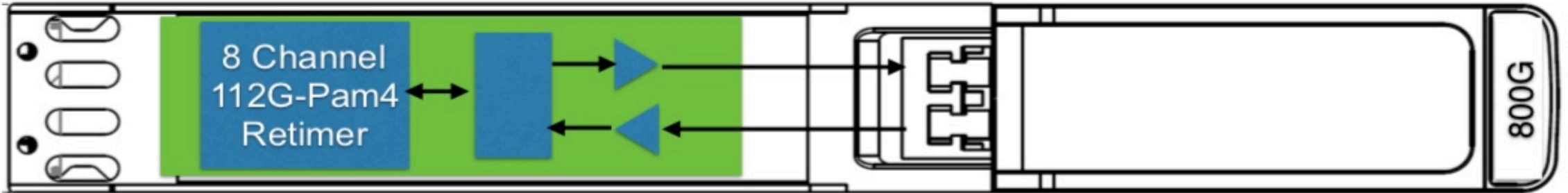
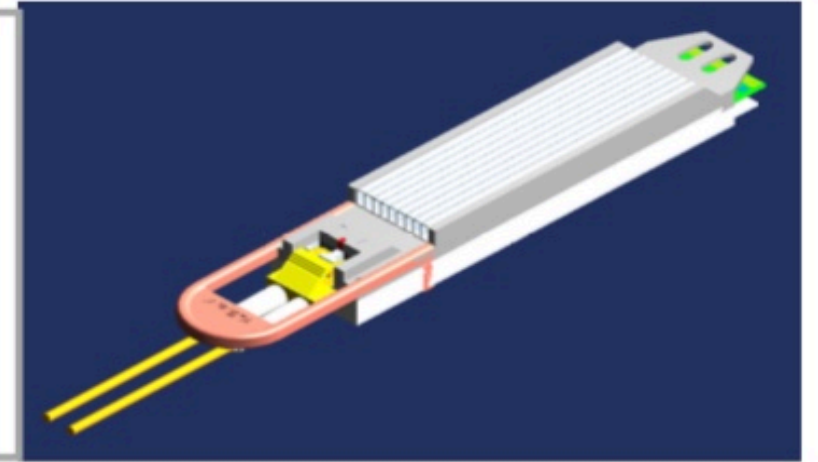
800G-FR8/LR8/CWDM8

800G-FR8/LR8/CWDM8

8x112G-PAM4 Electrical Interface

Duplex LC Fiber Connector

Estimated Power: 20W



800G or Dual 400G over Duplex Fiber

The OSFP (Octal Small Form Factor Pluggable)

High Port Density: UP to 36 per 1U

14.4T with 8x50G SerDes

28.8T with 8x100G SerDes

High Thermal Capability

Up to 20W Power Capability

Needed for 400G-ZR+ and 800G optics

Backward Compatible with QSFP

With Simple OSFP-QSFP Adaptor



 **OSFP**

The QSFP-DD (QSFP Double Density)

- **Eight Lanes at 56G-PAM4**
 - Supports 400G with 8x50G lanes
- **Port Density: 36 per 1U**
 - 14.4 Tbps per 1U
- **Stacked Connector Design**
 - Impacts Performance at 11G-PAM4
- **Thermal Capability**
 - Up to 15W Power per Module

QSFP-DD 

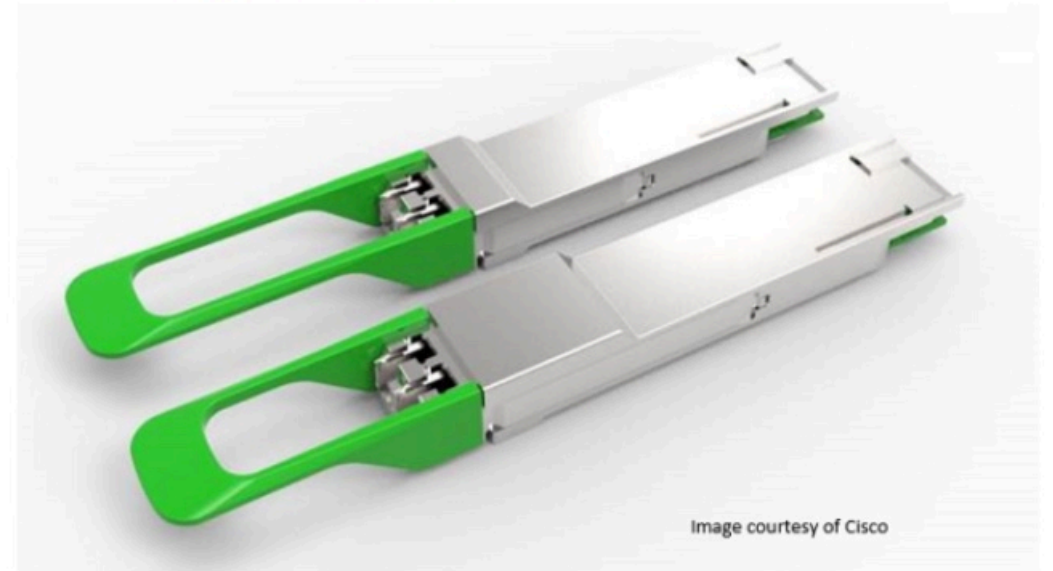


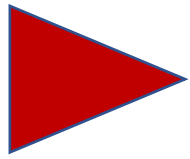
Image courtesy of Cisco

QSFP-DD Type 1 and Type 2 form factors.

OSFP, QSFP-DD and COBO @ 112G-PAM4

Module	Signal Integrity	Thermal Management	Copper Cable	Module Density	Backward Compatibility
OSFP	#1 in RL and and CrossTalk	Up to 20W per Module	26 AWG fits easily	36 per 1U	With QSFP Adaptor
QSFP-DD	#3 in RL and and CrossTalk	Up to 15W per Module	26 AWG is difficult	36 per 1U	Directly accepts QSFP Modules
COBO Onboard optics	#2 in RL and and CrossTalk	Up to 20W per Module	N/A	36 per 1U	No Backward Compatibility

In Summary



400G is the Next Major Step in Ethernet

- **4x the Bandwidth-Density of 100G Ethernet**
 - 2x the power efficiency and 2x the price-performance
 - Fewer Bigger Pipes are easier to manage
- **400G-ZR/ZR+ Optics will revolutionize optical transport**
 - Game Changing price-performance and density
 - Any Switch-router port can directly support 400G-ZR/ZR+
- **OSFP Optics Modules will support full-power 400G-ZR+**
 - Plus future 800G (dual 400G) optics modules that are fully compatible with 100G Lambda optics ecosystem



The Easiest Way to Go Faster is to go Faster

Ethernet Speed Transitions have been the primary driving force to improve the throughput and the price-performance of Service Provider and Data Center networks