Building the 400G Internet

Trends, Technologies and the Road to 800G+

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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

Cloud DC Need

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

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2012</th>
<th>2016</th>
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<tbody>
<tr>
<td><strong>Optical</strong></td>
<td>Transport</td>
<td>Transport</td>
<td>Transport</td>
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<tr>
<td><strong>Routing</strong></td>
<td>Core</td>
<td>Core</td>
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<td></td>
<td>Edge</td>
<td>Edge</td>
<td>Edge</td>
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<tr>
<td><strong>Switching</strong></td>
<td>Spine</td>
<td>Spine</td>
<td>Spine</td>
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<td></td>
<td>Leaf</td>
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- **Proprietary Chips**
- **Merchant Silicon**
Merchant Silicon Growth

Source: The 650 Group, Jan 2017
Single-Chip Switch Silicon Bandwidth Growth

[Bar chart showing growth in Gbps from 2008 to 2019. Key points include:
- 2008: 2.66X/3Y
- 2011: 2X/2Y
- 2013: 2.5X/2Y
- 2017 and 2019: 2X/2Y]
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
16 nm die 3X
7 nm die 15X
5 nm die 30X

Shipping Today
2018-19 Silicon
2020-21 Silicon
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

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-300km—1000km, high output-power, etc
400G-ZR+ Covers all of Europe with 400G-DWDM

400G-ZR+ Covers Most of USA with 400G DWDM

Internet-2 100G Research Network (May 2017)
Pluggable DCO Form Factor Transition to OSFP

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

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

400G-16QAM 1000km
36 per 1U (14.4T)
Coherent Bandwidth by Speed

4Q17 Optical Applications Report
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
  - OSFP: ✔️  
  - QSFP-DD: ✔️

- 20W Thermal Capacity for 400G-ZR+ and 800G
  - OSFP: ✔️  
  - QSFP-DD: ✗

- High Signal Integrity for 112G-PAM4 SerDes
  - OSFP: ✔️  
  - QSFP-DD: ✗

**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

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

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