Managing Digital Coherent Optics in Routers

Emerson Moura, Distinguished Architect

February, 2023

Acknowledgements

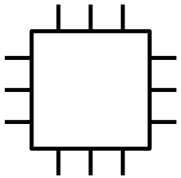
- This content has been created in collaboration with **Phil Bedard**, Principal Engineer, Cisco

Agenda

- Why Digital Coherent Optics?
- Technology Overview and Standards
- Management considerations for routers
- Wrap-up

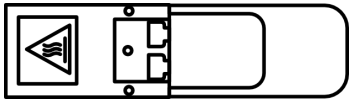
Why moving to 400Gbps is so important?

400Gbps brings Scale, Simplicity and Sustainability



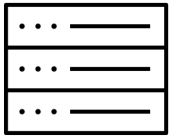
Silicon

- Enabling >10 Tbps / RU
- SoC and multi-purpose
- Lower power and footpring per bit



Optics

- QSFP-DD56 - best port density, excellent power/thermal profile
- Various reaches, Silicon Photonics and Digital Coherent Optics (DCO)



Systems

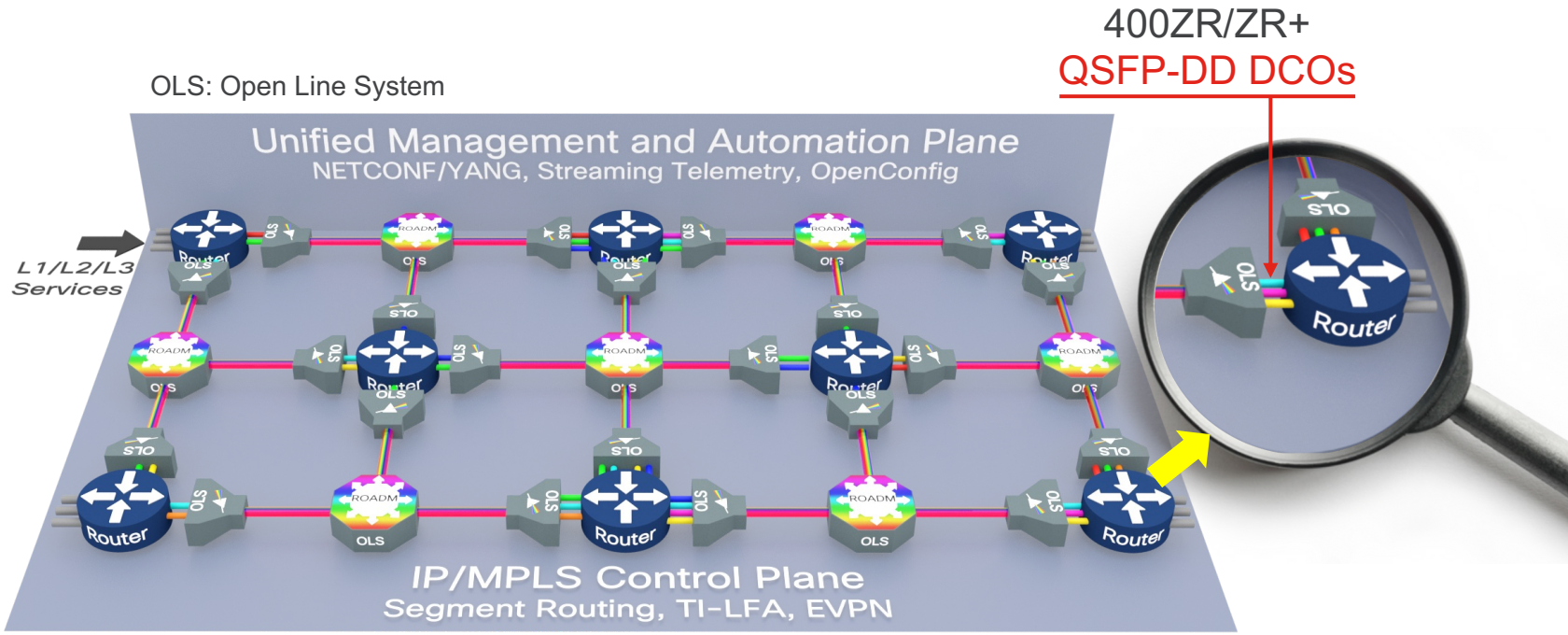
- System scalability
- 400G+ optimized designs
- Common platform for various use cases: fixed chassis, modular, centralized

Why Digital Coherent Optics for 400GE?

- Much harder to transmit over the fiber (n^2 problem)
- Coherent optics – best solution
- Digital coherent optics – better economics and sustainability
- Novel network architectures, i.e. Routed Optical Networking
- Compatible with standard router/switch hardware and existing DWDM systems

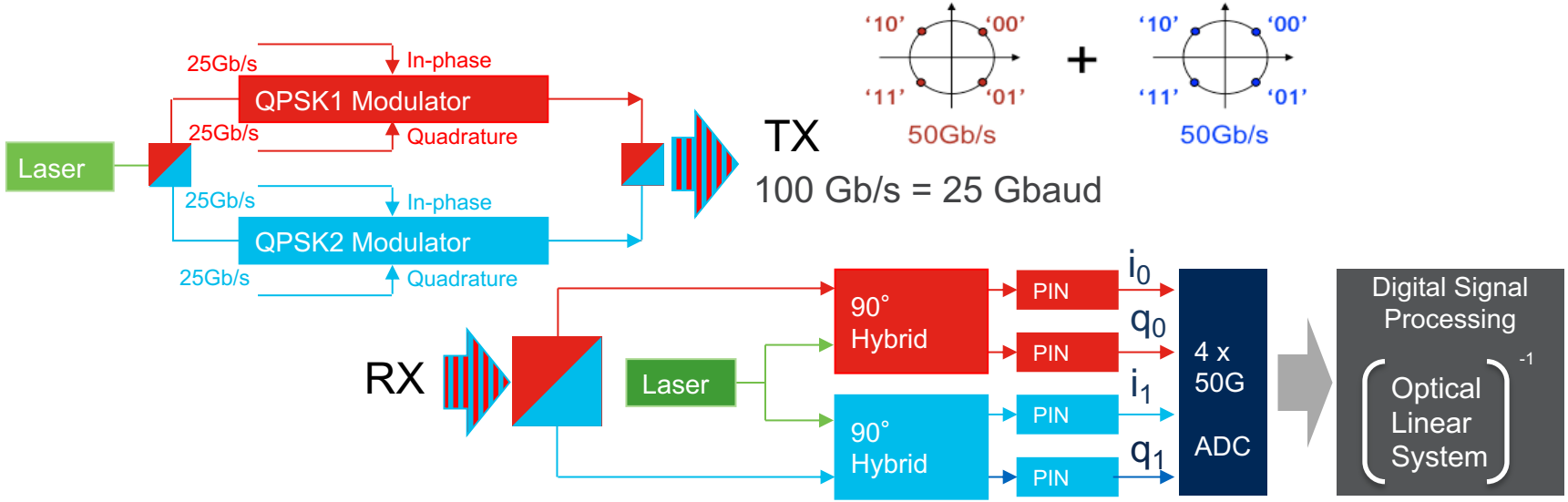
Business benefits of DCO vs DWDM transponders

Routed Optical Networking



Simplifies the network and lower costs. Enabled by DCO.

Coherent optics technology - 100Gbps Example

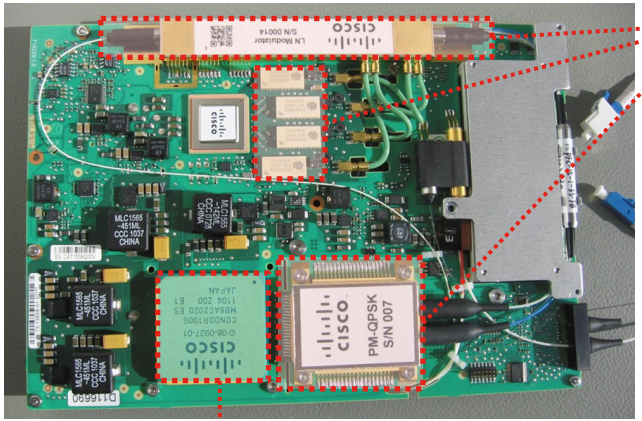


- Each polarization mode is modulated independently and carry different data (↑ data rate, ↓ symbol rate)
- Advanced Digital Signal Processing to address optical impairments

What is a DCO Transceiver ?

DCO = Digital Coherent Optic

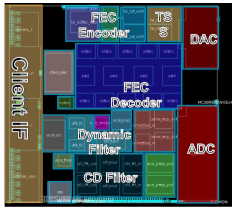
Typical 100G Coherent transponder line card for 300x300mm layouts



$$$

Discrete Photonic Elements

Digital Signal Processor



28nm

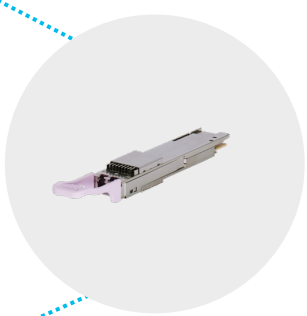
Silicon Photonics Integration Advanced Packaging Integration

Moore's Law

PIC with Multi Chip Packaging

7nm

QSFP-DD 400G DCO

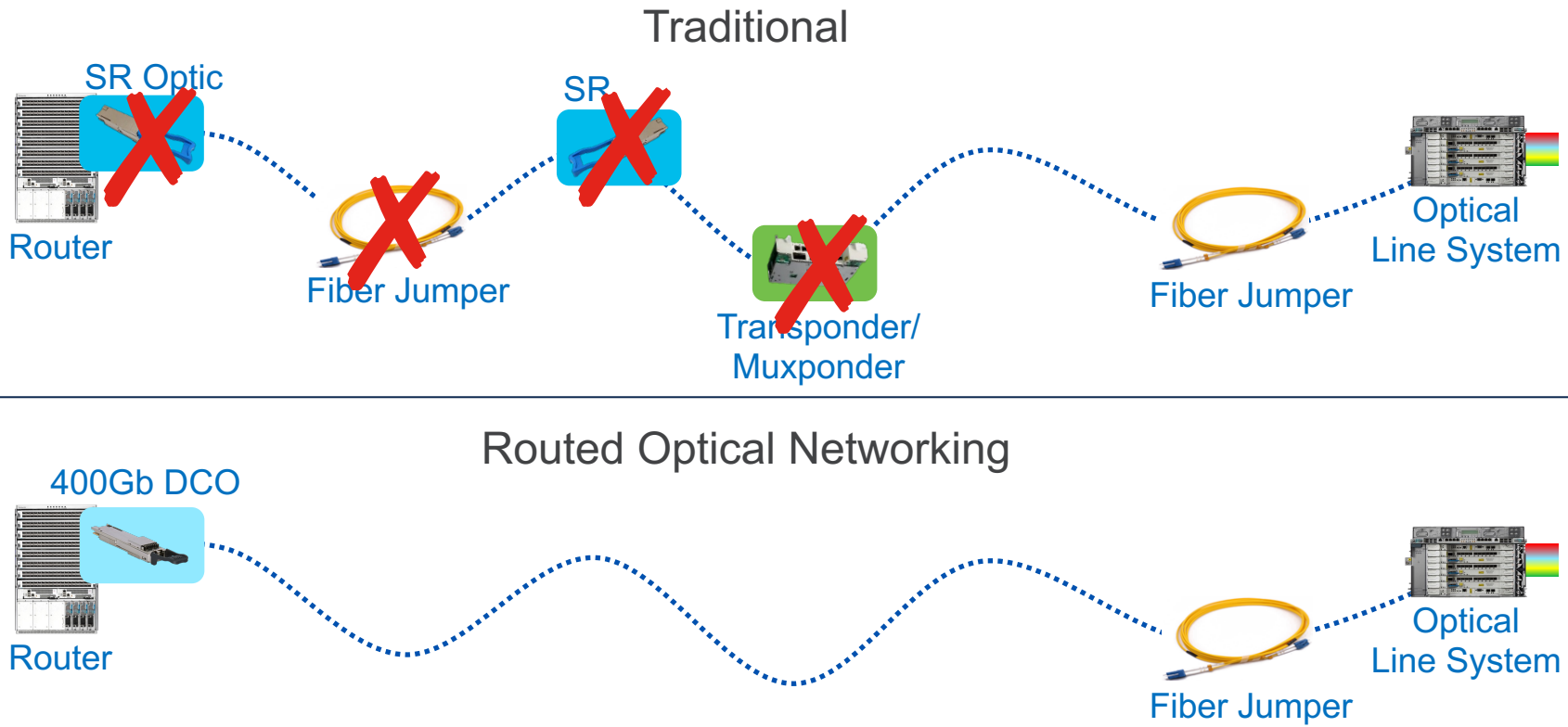


$

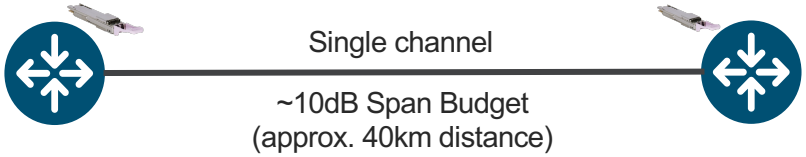
Uses standard 400GE host port

> 10x decrease in power/bit

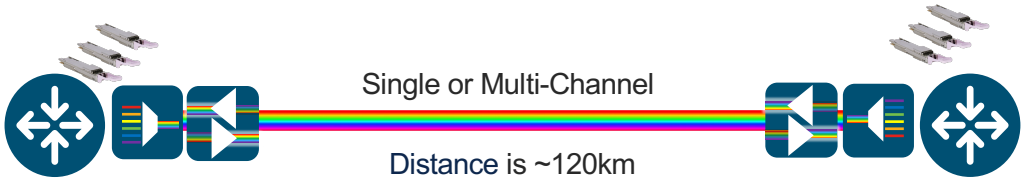
Removing hardware complexity and cost with DCO



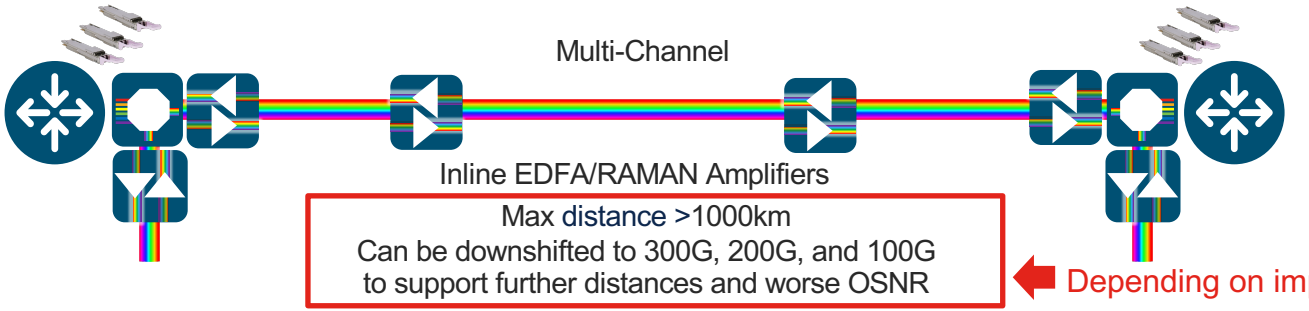
DCO Applications



Unamplified, Dark Fiber



Amplified, Point-to-point DWDM



Full featured DWDM
(ROADMs, ILAs)

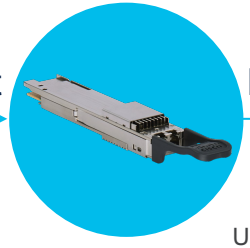
Depending on implementation/standard

400G DCO Standards and Industry Specifications

OIF 400ZR

Simplified functionality
Edge optimized FEC (C-FEC)

400GE → Client → Line → 400ZR



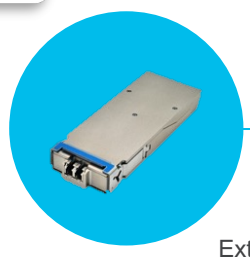
Up to 120km reach

Open ROADM

Flexible Client Mapping +
High Performance FEC (oFEC)

100G
200G
300G
400G
Ethernet
OTN
FlexO

→ Client →



→ Line →

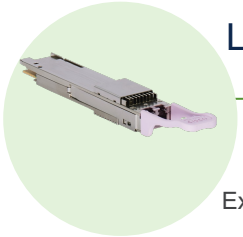
100G
200G
300G
400G
OpenROADM

Extended reaches

OpenZR+ MULTI-SOURCE AGREEMENT

100GE
200GE
400GE
Nx 100GE
(Muxponder Mode)

→ Client →



→ Line →

100G
200G
300G
400G

Extended reach

Simplified functionality +
High performance FEC (oFEC)

High performance pluggable modules
Multi-vendor interoperability

400G QSFP-DD 400ZR & OpenZR+ specifications

Reference

Enable a broad range of use cases: campus, metro/regional and long haul

Mode	Line Rate	Baud Rate	Modulation Format	FEC	Min. Channel Spacing	Min. TX Power	OSNR Tolerance	Min. RX Sensitivity	DGD Compensation	Max. CD Compensation
Unit	Gbps	GBaud			GHz	dBm	dB/0.1 nm	dBm	ps	ps/nm
 OIF ZR	400	59.8	DP-16QAM	CFEC	75	-8.5 (Typical) -10 (EoL)	26	-20	33	+/- 2400
 OpenZR+	400	60.14	DP-16QAM	OFEC	75	-10	24	-12	55	20,000
	300		DP-8QAM			-10	21	-15	66	40,000
	200		DP-QPSK			-9	16	-18	66	50,000
	100	30.07	DP-QPSK			-8	12.5	-18	83	100,000

Note: OpenZR+ MSA based on V2 specification – July 2022

400Gbps Pluggable DCOs configuration parameters

Reference

	400ZR	OpenZR+ (Cisco)
Client Speed	1x400, 4x100	1x400G, 4x100G, 3x100G, 2x100G, 1x100G
Trunk Speed	400G	400G, 300G, 200G, 1x100
Frequency	C-Band, 196.1 To 191.3 THz	C-Band, 196.1 To 191.3 THz
FEC	cFEC	oFEC, cFEC
Modulation	16QAM	16QAM, 8QAM, QPSK
DAC-Rate	1x1	1x1.25 (oFEC), 1x1 (cFEC)
Chromatic Dispersion (CD)	-2400 to +2400	-160000 to +160000
Transmitted (Tx) Power	Based on the module capability	Based on the module capability

Simplifying 400G pluggable DCO provisioning using configuration modes

Reference

Single integer value

DCO	Operational Mode	Line Rate	FEC Type	Modulation	Baud Rate	Pulse Shaping
OIF ZR	5003	400	cFEC	16QAM	59.84	No
OpenZR+	5004	400	cFEC	16QAM	59.84	No
	5005	400	oFEC	16QAM	60.14	Yes
	5006	400	oFEC	16QAM	60.14	No
	5007	300	oFEC	8QAM	60.14	Yes
	5008	300	oFEC	8QAM	60.14	No
	5009	200	oFEC	QPSK	60.14	Yes
	5010	200	oFEC	QPSK	60.14	No
	5011	200	oFEC	8QAM	40.10	Yes
	5012	200	oFEC	16QAM	30.08	Yes
	5013	100	oFEC	QPSK	30.08	No

DCO performance management (PM) parameters

Reference

Optics PM

PM Parameters	Description
CD	Chromatic dispersion
DGD	Differential group delay
LBC	Laser bias current in mA
FREQ-OFF	Low signal frequency offset in MHz
OPR	Optical power RX in µW or dBm
OPT	Optical power TX in µW or dBm
OSNR	Optical signal-to-noise ratio in dB
PCR	Polarization change rate
PDL	Polarization dependent loss
RX-SIG	Receiving signal power µW or dbm
SNR	Signal-to-noise ratio
SOPMD	Second order polarization mode dispersion

Coherent DSP PM

PM Parameters	Description
Q	Q factor
Q-margin	Q margin
EC-BITS	Error corrected bits
PostFEC BER	Post forward error correction bit error rate
PreFEC BER	Pre forward error correction bit error rate
UC-WORDS	Uncorrected words

Pluggable DCO transceivers provide detailed visibility of optical transport performance and fiber quality directly to the router (or host).

Sample PM counters output for optics

Reference

```
RP/0/RP1/CPU0:Ravello-51#sh controllers optics 0/0/2/2 pm current 30-sec optic$
Thu Dec 22 13:38:27.415 CET

Optics in the current interval [13:38:00 - 13:38:27 Thu Dec 22 2022]

Optics current bucket type : Valid
                 MIN       AVG       MAX      Operational      Configured      TCA   Operational      Configured     TCA
                                                Threshold(min)   Threshold(min) (min) Threshold(max)   Threshold(max) (max)
LBC[mA ]       : 73        73        73         0                NA              NO    131              NA             NO
OPT[dBm]       : -11.44    -11.44    -11.44     -15.09           NA              NO    0.00             NA             NO
OPR[dBm]       : -7.41     -7.37     -7.33      -30.00           NA              NO    8.00             NA             NO
CD[ps/nm]      : -928      -927      -926       -160000          NA              NO    160000           NA             NO
DGD[ps ]       : 2.00      2.46      3.00       0.00             NA              NO    80.00            NA             NO
SOPMD[ps^2]    : 21.00     44.96     70.00      0.00             NA              NO    2000.00          NA             NO
OSNR[dB]       : 31.20     31.35     31.50      0.00             NA              NO    40.00            NA             NO
PDL[dB]        : 1.00      1.07      1.10       0.00             NA              NO    7.00             NA             NO
PCR[rad/s]     : 0.00      0.00      0.00       0.00             NA              NO    2500000.00       NA             NO
RX_SIG[dBm]    : -7.95     -7.93     -7.90      -30.00           NA              NO    1.00             NA             NO
FREQ_OFF[Mhz]: -919        -908      -896       -3600            NA              NO    3600             NA             NO
SNR[dB]        : 18.00     18.21     18.50      7.00             NA              NO    100.00           NA             NO

Last clearing of "show controllers OPTICS" counters never
```

Sample PM counters output for DSP

Reference

```
RP/0/RP1/CPU0:Ravello-51#show controllers  coherentDSP 0/0/2/2 pm current 30-sec fec
Thu Dec 22 13:46:38.918 CET

g709 FEC in the current interval [13:46:30 - 13:46:38 Thu Dec 22 2022]

FEC current bucket type : Valid
    EC-BITS   : 0                     Threshold : 111484000000          TCA(enable)  : YES
    UC-WORDS  : 0                     Threshold : 5                     TCA(enable)  : YES

                                        MIN       AVG       MAX      Threshold      TCA     Threshold     TCA
                                                                       (min)      (enable)    (max)     (enable)
PreFEC BER                    :   7.3E-04   7.3E-04   7.3E-04         0E-15        NO       0E-15        NO
PostFEC BER                   :     0E-15     0E-15     0E-15         0E-15        NO       0E-15        NO
Q[dB]                         :     10.00     10.00     10.00         0.00         NO        0.00        NO
Q_Margin[dB]                  :      3.70      3.70      3.70         0.00         NO        0.00        NO

Last clearing of "show controllers OTU" counters never
```

How to manage and configure a DCO transceiver without CLI?

- Much more data to manage than grey optics
- Transport PMO is based on GUI
- End goal is automation, i.e. must be friendly for machine-to-machine communication
- Operators are embracing open/standard management frameworks

Open management and automation initiatives

OPENCONFIG

Over 30 companies
Webscales and CSPs

- Common data models (covers DCO pluggables)
- gRPC management protocol
- Subscription based streaming telemetry
- Vendor neutral testing and compliance

IETF®

- YANG language, NETCONF and RESTCONF protocols
- Consensus based data models, hackatons, catalog
- Abstraction and Control of Traffic Engineered Networks framework (ACTN – see next slides)

Open ROADM

- YANG models for disaggregated DWDM systems (covers DCO pluggables), RPCs and device templates
- Controller based archtiecture (see next slides)

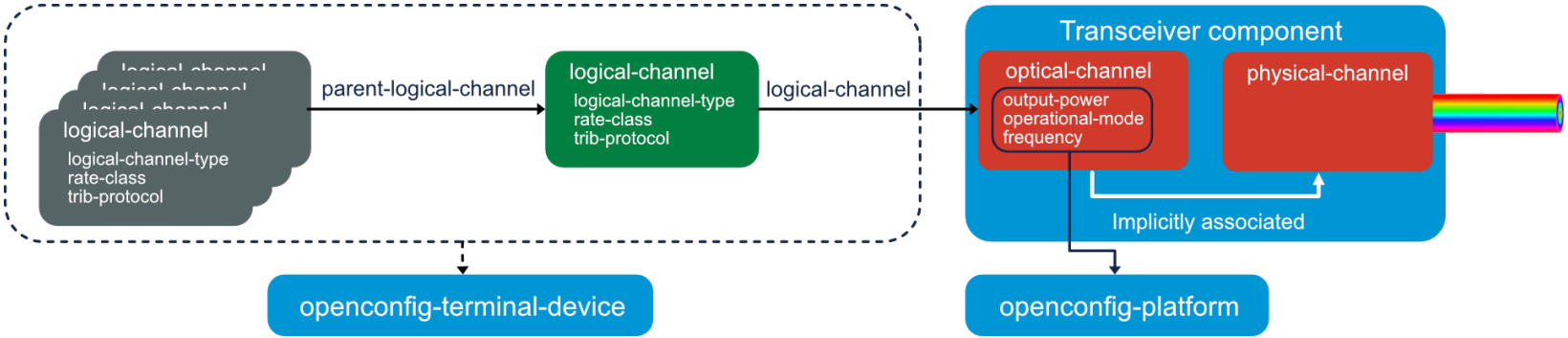
- MANTRA subgroup
- Aims to build an end-to-end reference network architecture based on Open Optical Networks (OON)
- Enabling “new generation” IPoDWDM with DCO

OpenConfig models for 400G DCO

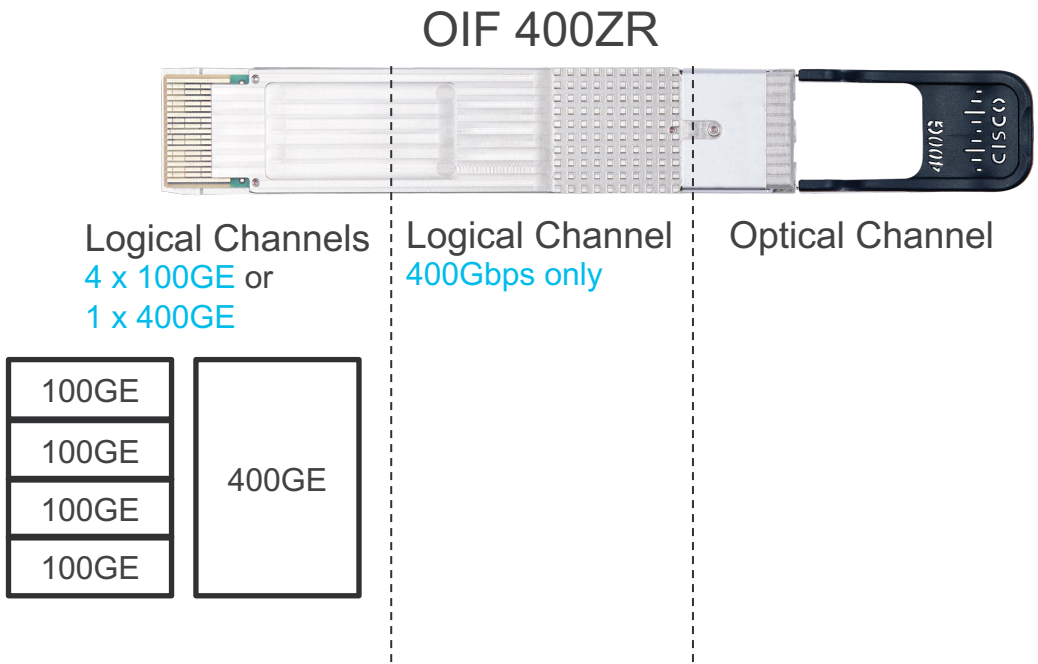
Model	Use
openconfig-terminal-device	Primary model used to configure input interface to output line port structure and add optical parameters to oc-platform
openconfig-platform	Used to provision optical channel parameters and for monitoring optical channel state
openconfig-platform-transceiver	Used for monitoring physical channel state data such as RX/TX power, and output frequency

Note: This list is only the parent models utilized and does include imported models.

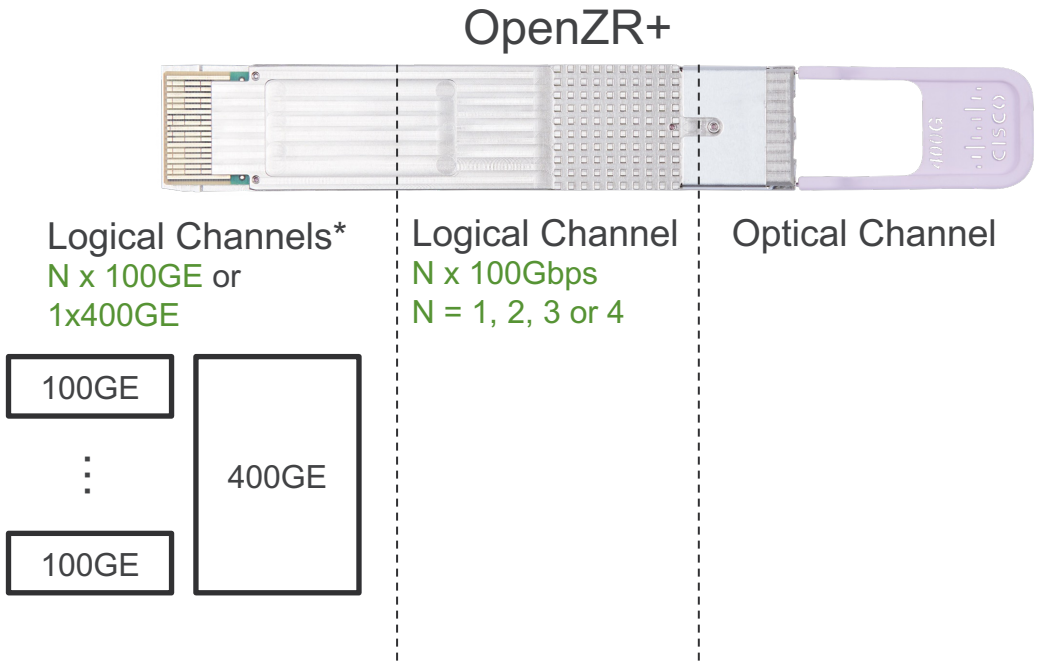
OpenConfig DCO model logical view



OpenConfig hierarchical structure mapped to pluggable DCO



OpenConfig hierarchical structure mapped to pluggable DCO



Note: OpenZR+ MSA specification also supports 200G mapping over 200G-400G logical channels

Sample optical channel config using OpenConfig platform component

```
<components xmlns="http://openconfig.net/yang/platform">
    <component>
        <name>0/0-OpticalChannel0/0/0/10</name>
        <config>
            <name>0/0-OpticalChannel0/0/0/10</name>
        </config>
        <optical-channel xmlns="http://openconfig.net/yang/terminal-device">
        <config>
            <target-output-power>-10.00</target-output-power>
            <frequency>196100000</frequency>
            <operational-mode>5005</operational-mode>
        </config>
        </optical-channel>
    </component>
</components>
```

Target output power in dBm

Optical channel frequency in MHz

Operational mode

Full configuration example using NETCONF: https://xrdocs.io/design/blogs//zr-openconfig-mgmt

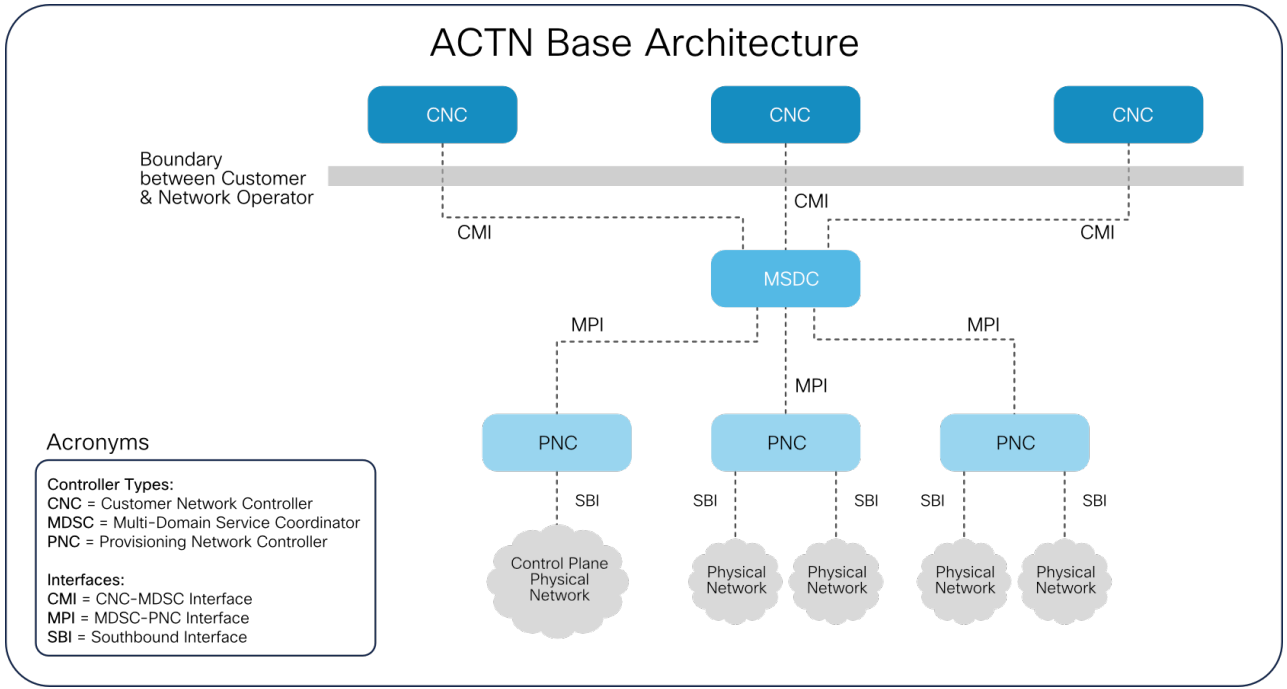
Sample model driven telemetry data using gNMI


```
[
  {
    "source": "172.29.11.20:57733",
    "timestamp": 1664644343717885105,
    "time": "2022-10-01T13:12:23.717885105-04:00",
    "updates": [
      {
        "Path": "openconfig-platform:components/component[name=0/0-OpticalChannel0/0/0/8]",
        "values": {
          "components/component": {
            "config": {
              "name": "0/0-OpticalChannel0/0/0/8"
            },
            "openconfig-terminal-device:optical-channel": {
              "Cisco-IOS-XR-openconfig-terminal-device-ext:extended": {
                "state": {
                  "optics-cd-high-threshold": 160000,
                  "optics-cd-low-threshold": -160000,
                  "optics-cd-max": 13000,
                  "optics-cd-min": -13000
                }
              },
              "config": {
                "frequency": 193700000,
                "operational-mode": 5005,
                "target-output-power": "-115"
              },
```


Note: Ouput cut for brevity.

Modernizing Management and Automation

Goal: open architectures, APIs and data models



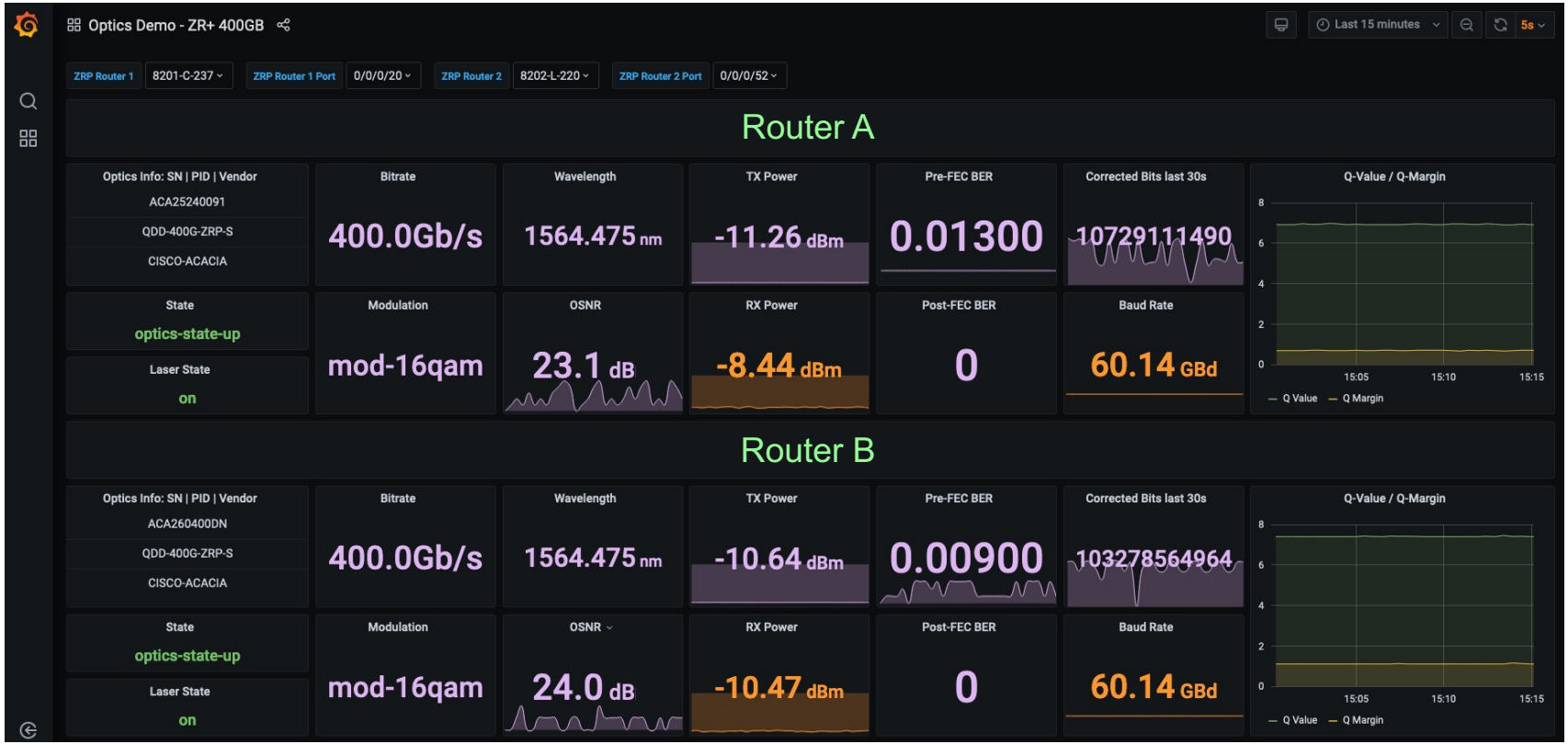
Streaming telemetry for pluggable DCO transceivers

```
telemetry model-driven
 include select-leaves-on-events
 destination-group pipeline
  address-family ipv4 172.27.223.244 port 5432
   encoding self-describing-gpb
   protocol tcp
  !
 !
 sensor-group optics
  sensor-path Cisco-IOS-XR-controller-otu-oper:otu
  sensor-path Cisco-IOS-XR-controller-optics-oper:optics-oper
  sensor-path Cisco-IOS-XR-pmengine-oper:performance-management/otu
  sensor-path Cisco-IOS-XR-pmengine-oper:performance-management/optics
 !
 subscription optics-sub
  sensor-group-id optics sample-interval 30000
  destination-id pipeline
  source-interface MgmtEth0/RP0/CPU0/0
```

Data you want to monitor

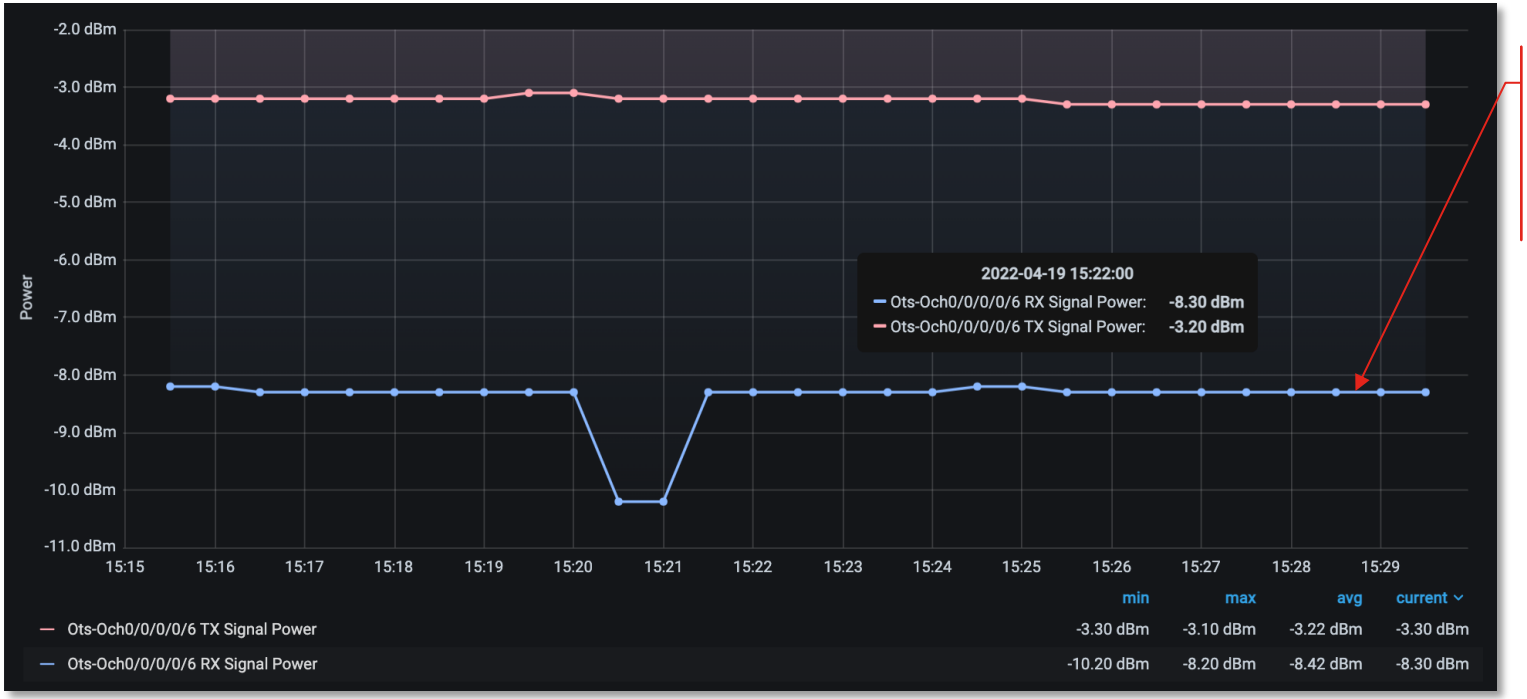
Pub/sub model

DCO monitoring using open-source Grafana



DCO monitoring using open-source Grafana

Streaming telemetry provides data at higher frequency



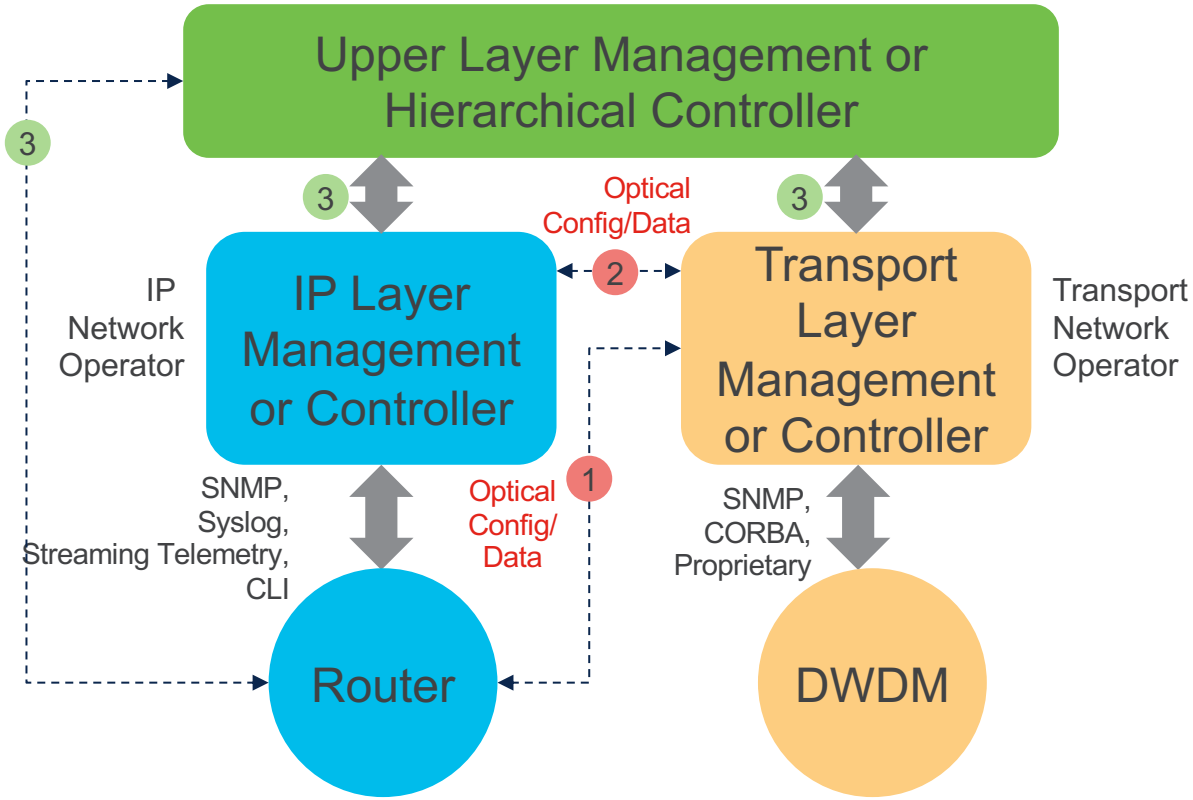
Example

30 sec
vs
15 min

Additional considerations

- Logical split of DCO allows different groups to configure and manage them individually:
  - Ex: Transport > Coherent DSP and Optics
    IP > Logical interfaces (Ethernet)
    Enabled by NETCONF (RBAC for subtrees in the data model)
- Same applies to connecting each components to a different tool or controller
- This is not a solution for the past closed/proprietary systems, but for the future of open systems

Integration options



1. Requires transport vendor collaboration for integration (e.g. via SNMP)

2. Requires transport vendor collaboration for integration (e.g. via RESTConf, SNMP NBI)

3. Well-known approach which relies on open APIs/data models for integration (e.g. via RESTConf, gNMI, T-API)

Managing Digital Coherent Optics in Routers

Summary

- Vendor solutions and open source tools are available to manage DCO enabled networks via streaming telemetry
- Data models available from multiple industry consortia supporting different use cases
  - OpenConfig
  - Open ROADM
- Excellent opportunity to depart from closed, proprietary management systems
  - DCO management and automation perfectly aligned with industry push towards open systems and SDN architectures

The bridge to possible