400ZR Interoperability White Paper
ECOC 2022 Plugfest

11/2/2022

ABSTRACT: This paper presents an initial investigation into interoperability between high speed 400Gb/s QSFP-DD coherent transceivers through a dense wavelength-division multiplexing (DWDM) color link in an optical line system. These transceivers meet the OIF-400ZR Implementation Agreement (IA) and can establish optical links over an 80km span in 75Ghz grid DWDM transmission system. Multiple combinations of transceivers were taken from different module vendors to compare transmitter (Tx)-to-receiver (Rx) pairing performance, including the pairing of different digital signal processing (DSP) chip designs. The test was performed to find the error-free threshold of the 400Gb/s links, while monitoring the optical signal to noise ratio (OSNR). In each Tx-to-Rx combination, the OSNR was artificially reduced until post-FEC errors appeared, providing guidance on the required OSNR (rOSNR). Additionally, the Common Management Interface Specification (CMIS) Versatile Diagnostic Monitoring (VDM) reporting mechanism of average OSNR was captured from each module and evaluated against the measured OSNR by a high-resolution optical spectrum analyzer (OSA). This investigation was conducted during a plugfest (hosted by Nokia-Paris Saclay) of the 400ZR demo for ECOC 2022 and supported by all participants.

1 Introduction

The OIF continues to play a key role in the standardization of coherent optics at the physical layer with the development and maturity of the OIF-400ZR Implementation Agreement. The OIF-400ZR IA has transitioned coherent optical modules toward a cost-effective model. The OIF-400ZR IA provides a framework for the optical interface requirement of 400Gb/s traffic based on single-carrier coherent DP-16QAM modulation format and structures the supporting Concatenated FEC (C-FEC). This OIF-400ZR IA has benefitted from existing OIF IAs that cover component performance for the transmitter and receiver, while allowing the flexibility to support multiple form-factors. Additionally, the maturity of the low power 7nm DSP chip has provided a path for vendors to build the smaller QSFP-DD and OSFP form factor modules, enabling high density data center interconnect architecture.

The industry has moved past the initial phase of testing the base functionality of QSFP-DD and OSFP 400ZR modules, which are widely available for network operators from multiple vendors. Network operators are now seeking a healthy ecosystem where these pluggable modules can interoperate 400Gb/s traffic link between multiple vendors. While several “bonus” measurements were suggested by network operators, we determined that the key optical performance interop parameter is the OSNR threshold, which is the module’s ability to receive a signal when noise is introduced from the optical line system.

This paper investigates the OSNR performance impact when seven different vendors pair their OIF-400ZR QSFP-DD transmitters and receivers together over an optical line system. By controlling the noise level of the signal, we can find the OSNR threshold, or rOSNR value, which is needed to maintain a post-FEC error free link. Additionally, we evaluated the module’s reporting accuracy of the average OSNR through the CMIS VDM registers when paired with different transmitters. The goal is to provide confidence to network operators that multiple 400ZR vendors can be monitored together in future 400ZR DWDM links.

2 Test Setup

The interoperability test setup utilized a combination of optical network equipment from different vendors, per Figure 1. The optical line system was built with a combination of Cisco and Nokia equipment. Two Cisco NCS 1001 DWDM 64-channel 75Ghz patch panels were used for the mux/demux and a Cisco NCS 1001 DWDM line system was used for the pre-erbium-doped fiber amplifier (EDFA) gain. The Nokia 1830 PSI-L optical line system was used for the post-EDFA amplification gain. Both amplifiers were operating in a constant gain mode.

All the test equipment was provided by EXFO. The EXFO LTB-8 mainframe provided the host dual port interface for the QSFP-DD modules. The EXFO DCO BERT application generated and evaluated the 400Gb/s traffic across the OIF-400ZR link. In between the Nokia post-EDFA amplification gain and the demux, two 50/50 splitters were introduced. One 50/50 splitter allowed a controlled ASE source and the other allowed OSNR measurements with the EXFO high resolution OSA (0.33nm resolution for acquisition, OSNR normalized at 0.1nm according to IEC 61280-2-9). The input signal into the receiver module’s receiver was dynamically controlled to -10dBm for all 400Gb/s links through the EXFO BI-variable attenuator with embedded power monitoring.

This investigation was conducted during a plugfest (hosted by Nokia-Paris Saclay) of the 400ZR demo for ECOC 2022 and supported by all participants.

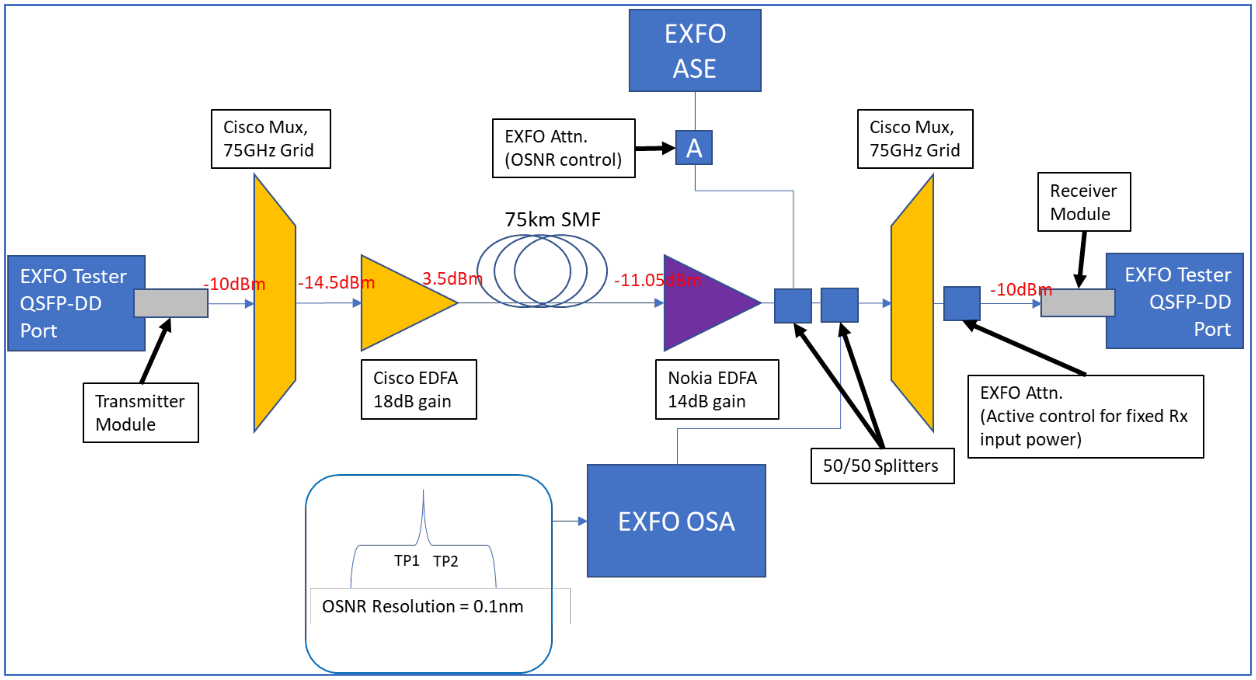

Figure 1 OIF 400ZR Plugfest Test Setup

3 Test Procedure

The interop test data compares different combinations of QSFP-DD OIF-400ZR links over a DWDM optical line system. First, the transmitter module was configured by the host to channel 24 (197.3THz) and the Tx output power was set to -10dBm using the module CMIS registers. The transmitter module would remain fixed in the same configuration, while the receiver modules were rotated from all vendors. In the case of the same vendor for the transmitter and receiver modules, different modules were used. A back-to-back link was connected from the receiver module's Tx to the transmitter module's Rx to ensure the OIF-400ZR link was established between the two vendor's 400ZR QSFP-DD modules.

Next the line system link was configured to have a high OSNR (>30dB) to ensure the OIF-400ZR link was established between both modules. The OSNR was degraded using the EXFO ASE and attenuator, marked 'A' in Figure 1, in 0.1dB steps until a post-FEC errors was reported by the host. At this state, the OSNR was increased by 0.1dB and traffic was monitored for 10 seconds. If the traffic remained error-free, then the module's CMIS VDM data was captured by the host. The line system OSNR level was measured and captured by the OSA. However, if a post-FEC error was reported by the host during the 10 second traffic soak, then the OSNR was increased by an additional 0.1dB and traffic was monitored for new period of 10 seconds. This 0.1dB increase in OSNR was repeated until the traffic remained post-FEC error-free for a 10 second period.

This rOSNR test process was repeated until all receivers were tested. Then the transmitter module was replaced with a different vendor until all link combinations were tested.

4 Test Data

The data presents two parameters the rOSNR threshold and the receiver module's CMIS VDM reporting accuracy. Figure 2 displays the rOSNR value over the DWDM optical line system link between each transmitter paired with each receiver. The recorded value in Figure 2 was measured by the OSA after the 10 second error-free traffic period. Figure 3 provides a visual comparison of a single vendor's rOSNR performance against the multi-vendor rOSNR data set. The x-axis values (in Figure 3) were taken from the highlighted cells in Figure 2 and are considered a reference point of performance since the transmitter and receiver modules came from the same vendor.

The data shows a significant variation in rOSNR when different vendors are paired together vs single vendor links. During the 10 second soak period, most vendor combinations can meet the OIF-400ZR IA Rx OSNR requirement of ≤26dB. However, six vendor pairs exceeded the rOSNR limit with values ranging from 26.3dB to 30.6dB.

Figure 4 provides a comparison between the measured OSNR value on the OSA and the reported OSNR value by module. The last table in Figure 4 highlights the difference between both OSNR values. The module's reported average OSNR, through the CMIS VDM registers, did show a variation when compared against the measured OSNR value on the OSA. The difference between the CMIS VDM registers and the OSA measured value, the delta, ranged from 0 to 17.6. Three vendors were able to maintain a delta below 1.5 for all combinations, with one vendor's delta staying below 1 for all combinations.

		Transmitter						
		A	B	C	D	E	F	G
Receiver (dB)	A	22.9	23.2	23.1	23.2	24.1	22.6	22.9
	B	23.5	23.7	24.0	25.0	24.3	23.2	23.2
	C	23.6	24.5	23.8	23.7	28.5	23.4	23.6
	D	24.2	25.1	24.8	24.2	30.6	23.7	24.0
	E	23.7	23.8	24.3	25.5	24.4	23.2	23.4
	F	25.3	25.1	25.8	29.7	26.4	24.4	24.6
	G	25.7	25.4	25.9	29.5	26.3	24.6	24.7

Single Vendor rOSNR of Rx

Figure 2 OIF 400ZR rOSNR Interop Test Results

[Single Vendor defined as: same vendor, but different Tx and Rx modules. Not loopback]

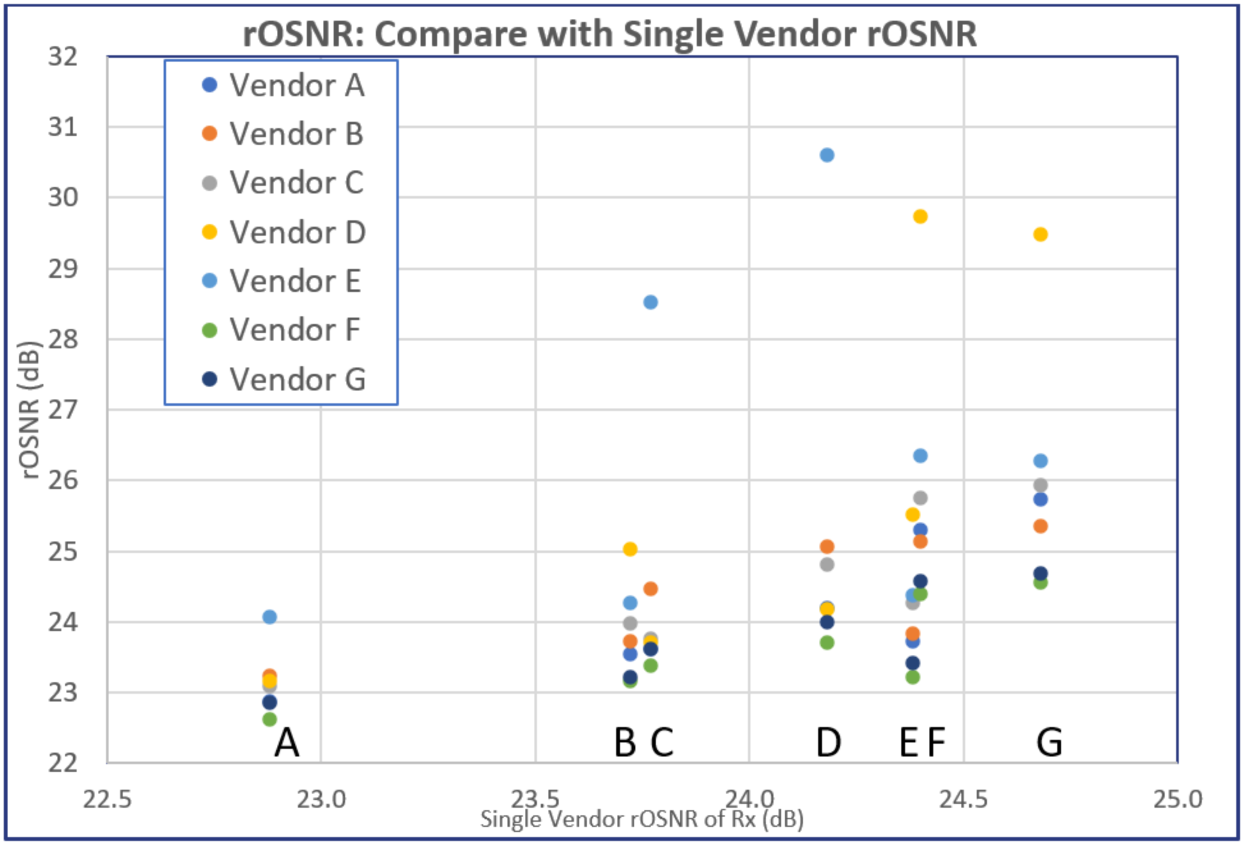

Figure 3 OIF 400ZR Visual Comparison of Single Vendor rOSNR vs Interop rOSNR Test Results

[Same Vendor ID definition as Figure 2]

Measured by OSA		Transmitter						
		A	B	C	D	E	F	G
Receiver (dB)	A	22.9	23.2	23.1	23.2	24.1	22.6	22.9
	B	23.5	23.7	24.0	25.0	24.3	23.2	23.2
	C	23.6	24.5	23.8	23.7	28.5	23.4	23.6
	D	24.2	25.1	24.8	24.2	30.6	23.7	24.0
	E	23.7	23.8	24.3	25.5	24.4	23.2	23.4
	F	25.3	25.1	25.8	29.7	26.4	24.4	24.6
	G	25.7	25.4	25.9	29.5	26.3	24.6	24.7

Rx Average OSNR Reported by Module CMIS VDM		Transmitter							
		A	B	C	D	E	F	G	
Receiver (dB)	A	24.0	23.0	22.9	23.0	23.2	22.9	22.9	
	B	25.0	24.1	24.1	24.3	23.6	23.4	23.3	
	C	23.4	23.0	23.5	22.8	23.8	23.0	22.8	
	D	23.5	23.5	21.4	23.5	23.8	23.4	23.5	
	E	26.5	28.8	26.0	26.9	26.0	26.0	26.0	
	F	25.4	24.8	25.2	29.2	25.5	24.6	24.8	
	G	15.1	11.2	11.8	11.9	11.2	24.6	24.6	Old firmware suspected.

Delta (dB)		Transmitter							
		A	B	C	D	E	F	G	Δ average
Receiver	A	1.1	0.2	0.2	0.2	0.9	0.3	0.0	0.4
	B	1.5	0.4	0.1	0.7	0.7	0.2	0.1	0.5
	C	0.2	1.5	0.3	0.9	4.7	0.4	0.8	1.3
	D	0.7	1.6	3.4	0.7	6.8	0.3	0.5	2.0
	E	2.8	5.0	1.7	1.4	1.6	2.8	2.6	2.6
	F	0.1	0.3	0.6	0.5	0.9	0.2	0.2	0.4
	G	10.6	14.2	14.1	17.6	15.1	0.0	0.1	10.2

Figure 4 OIF 400ZR Module Reported CMIS: VDM OSNR compared to Measured OSNR

6 Summary

The OIF 400ZR QSFP-DD interoperability test shows that all seven vendors can maintain 400Gb/s traffic over a DWDM optical line system as defined in the OIF-ZR IA. While these tests were limited in scope of soak time, the results can give network users confidence to perform their own in-depth evaluation with different module vendors. There was an observable difference in rOSNR between different combination of 400ZR QSFP-DD modules so additional testing is suggested. The OIF-400ZR QSFP-DD modules can report an average OSNR values within a reasonable limit when linked in different combinations, with one exception. These CMIS VDM reported OSNR values can be uses for basic guidance, but it is recommended to use a high resolution OSA while testing the rOSNR of OIF-400ZR links in an optical line system.

The OIF 400ZR module market has transitioned from the initial phase of basic functionality into an interoperable 400ZR ecosystem.

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Company	Ciena
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7 References:

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8 Appendix A: List of Contributors

Ciena - Gary Wang - WaveLogic 5 Nano 400ZR QSFP-DD

Cisco - Matteo Pierpaoli - 400ZR QSFP-DD, NCS 1001 DWDM Line System, NCS 1001 Mux/Demux Patch Panel

EXFO - Jean-Marie Vilain, Nicolas Carlier, Gwenn Amice - End to End Transmission & Optical Test Bench:

- LTB-8 Mainframe
- FTBx-88460 hosting QSFP-DD Dual port with DCO Bert Application
- FTBx-5255 optical spectrum analyzer
- 2 x FTBx-3500-BI variable attenuator with embedded power monitoring
- 2 x FTBx-9600 utility module with optical splitters
- AEDFA-NS2380 ASE source

Fujitsu - Hideki Isono, Atsuchi Yasuyuki - 400ZR QSFP56-DD

Juniper - Jose Aris Dimabuyu (JAD) - JCO400-ZRi 400ZR QSFP-DD

Lumentum - Doug Cattarusa - 400ZR QSFP-DD-DCO

Marvell – Janos Oeser, Chris Wong – COLORZ II 400ZR QSFP-DD

Nokia - Abdelali El Imadi, Julie Guihard - 400ZR QSFP-DD DCO, 1830 PSI-L Optical Line System

O-Net - GuoChu Zhou, Weihao Lin - 400ZR QSFP-DD

9 Appendix B: Glossary

400ZR - Digital Coherent Optical physical interface defined in the OIF-400ZR implementation agreement

BERT - Bit Error Rate Tester

C-FEC - Concatenated Forward Error Correction

CMIS - Common Management Interface Specification

DP-16QAM – Dual Polarization 16 state Quadrature Amplitude Modulation

DSP - Digital Signal Processor

DWDM - Dense Wavelength-Division Multiplexing

EDFA - Erbium-Doped Fiber Amplifier

FEC (post-FEC) - Forward Error Correction (after the Forward Error Correction process)

Gb/s - Gigi bit per second

IA - Implementation Agreement

OSA - Optical Spectrum Analyzer

OSNR - Optical Signal to Noise Ratio

QSFP-DD - Quad Small Form Factor Pluggable Double Density

rOSNR - required OSNR

Rx - Receiver

Tx - Transmitter

VDM - Versatile Diagnostic Monitoring

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Based on established methodologies including the documentation of industry requirements, bringing forward member-driven technical solutions, validation testing and free publishing, OIF's interoperability solutions are vital to the global network.

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