Demonstration of 400G High Power ZR+ IP over WDM in Key Network Scenarios with End-to-End 400GE Traffic

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Abstract: We show successful demonstration of emerging 400G high power ZR+ optics in IP over WDM applications investigating its performance in key network scenarios with end-to-end 400GE traffic and streaming telemetry for performance monitoring. © 2024 The Author(s)

1. Introduction

Network traffic continue to grow exponentially driven by high speed broadband, 5G services, video, cloud and data center applications. To ensure that networks can deliver high capacities efficiently to meet the increasing bandwidth demands, extensive research and development have been carried out on technologies beyond 100G, leveraging advanced modulation formats and higher baud rates [1-2], with 200/400G being deployed in the networks, higher speeds beyond 400G, e.g., 800G and Terabit single carrier, are rapidly emerging [3], which will further improve spectral efficiency and network capacities. In parallel, advanced coherent technology has been developed in recent years for shorter reach data center interconnect and metro applications where cost, space and interoperability are key priorities. Digital coherent optics (DCO) in pluggable modules are developed for high speed WDM interfaces, initially at 100/200G [4]. 400ZR, for transporting 400GE beyond reaches for client optics, is the first industry standardized DCO approved by OIF [5], enabling cost-effective implementation and multi-vendor interoperability. 400G ZR+, with its specification developed in OpenZR+ MSA, provides enhanced performance and functionalities over OIF 400ZR. 400G ZR/ZR+ coherent transceivers have been implemented in compact modules of same form factors as 400GE client optics in QSFP-DD/OSFP. This allows for new high speed IP over WDM network, the potential cost, space and power savings make it an attractive solution for future transport of IP network traffic. The latest development is 400G ZR+ optics with high transmitter output power (~0dBm) as defined in OpenZR+ specification v.3.0 [6], which address the low transmitter output power associated with the first generation of 400G ZR/ZR+ optics. In this paper, we show successful demonstration of emerging 400G high power ZR+ optics in IP over WDM applications. Different network scenarios key to network operators are investigated including (a) point to point WDM link of 310km, (b) 310km WDM link with flexible grid WSS (Wavelength Selective Switches), representative of ROADM based network links and (c) dark fiber link up to 120km. We show long term error free performance with end-to-end 400GE traffic and large optical margin for further extended optical reach. Error free performance of 400G high power ZR+ WDM wavelengths at spacings as narrow as 61GHz has been achieved showing robust performance with potential for improved spectral efficiency over standard 75GHz spacing. We also demonstrate streaming telemetry for performance monitoring in IP over WDM network.

2. Configuration of 400G high power ZR+ IP over WDM demonstration

Fig. 1a shows experimental configuration of 400G high power ZR+ IP over WDM demonstration, where Cisco 400G high power (bright) ZR+ optics, compliant to [6], are used as network interfaces in Cisco 8202 IP router (Fig. 1b), which is configured as two virtual routers. Optical links provide connectivity between the virtual routers via the 400G bright ZR+ network interfaces. To investigate key network scenarios and use cases, different optical links are

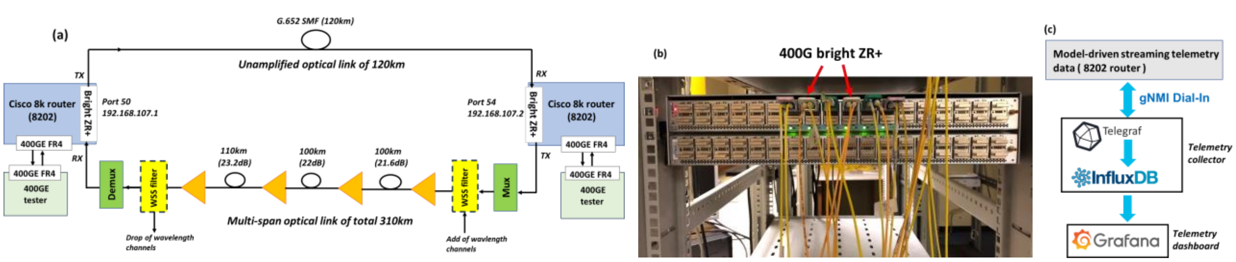


Fig. 1. 400G high power ZR+ IP over WDM demonstration: (a) system configuration, (b) 400G high power (bright) ZR+ optics operating in 8202 IP router and (c) schematic of model-driven telemetry.

set up: (a) point to point multi-span WDM link of total 310km using standard G.652 SMF and EDFA amplification, (b) WDM link of total 310km with flexible grid WSS (1×9) filters inserted for wavelength add/drop, a representative ROADM based network link, and (c) unamplified dark fiber link with standard G.652 SMF up to 120km. In the WDM links, multiplexer/demultiplexer with 75GHz spacing are used to combine/separate optical channels including 400G high power ZR+ wavelengths. 400G high power ZR+ transceiver uses DP-16QAM modulation format and a high baud rate of ~60.1GBaud [6], it has high transmitter output power which is configurable [7] with its power range measured between -10 and 2dBm. 400GE testers are used to generate and deliver traffic to/from virtual routers via traffic ports using 400GE FR4 client optics. 400GE traffic of different frame configurations, e.g., random frames and fixed frames of various sizes, are used for end-to-end performance measurement. Fig. 1c shows a schematic of model driven telemetry using standards-based Yang data models in the router. Telemetry data are exported from the IP router via gNMI (gRPC Network Management Interface) to a telemetry collector set up using open source software Telegraf and InfluxDB [8]. Grafana Dashboard is used to visualize the telemetry data. Streaming telemetry provides performance monitoring of 400G high power ZR+ signals at finer granularity, set to 30s interval in our demonstration, key performance parameters include pre-FEC and post- FEC BER, signal powers, chromatic dispersion, PMD and optical signal to noise ratio (OSNR) as well as data and packet rates.

3. Experimental demonstration results

We investigated single channel performance of 400G high power ZR+ over the 310km point to point WDM link, where the transmitter power is set to -8dBm. In Fig. 2, we show pre-FEC BER performance as a function of signal power into transmission link (Fig. 2a) and the corresponding link OSNR (Fig. 2b). We see that at lower signal power from -1dBm, pre-FEC BER improves quickly as signal power increases resulting in increased link OSNR. When the signal power further increases beyond ~4dBm, pre-FEC BER improves less due to increased fiber nonlinear effects, the optimum power is ~6dBm. Fig. 2c shows long term error free performance at different power levels. At a normal operating signal power of 3.8dBm corresponding to a link OSNR of ~28dB, pre-FEC BER is ~1.9×10^{-3}, well below the error free threshold of 2×10^{-2}, giving ~6.3dB optical margin compared with the measured minimum required OSNR for error free performance, thereby allowing for extended reach. At a low power level of -0.3dBm, pre-FEC BER is ~7.3×10^{-3} with a clear margin (>2dB) from the error free threshold suitable for practical application.

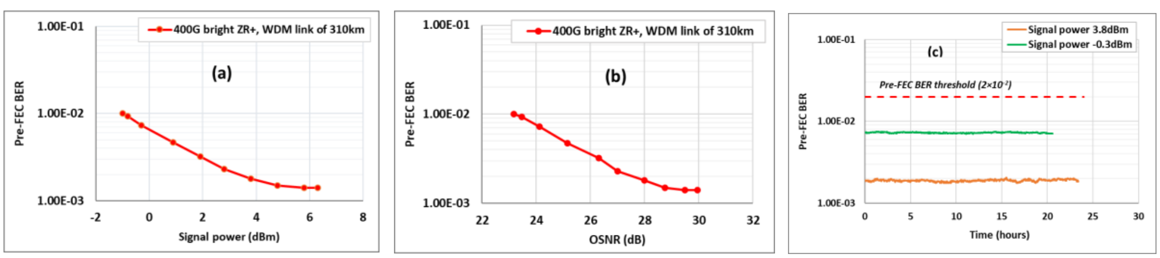
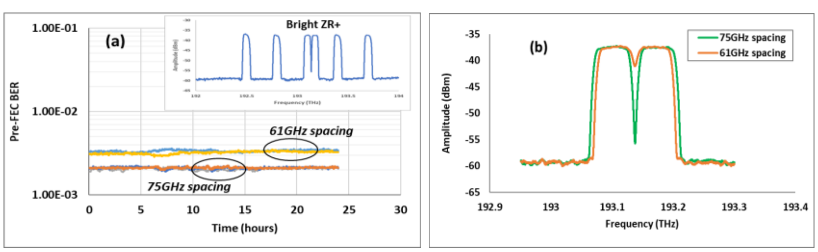


Fig. 2. Performance of 400G high power ZR+ over 310km point to point WDM link: (a) pre-FEC BER vs signal power, (b) pre-FEC BER vs link OSNR and (c) long term pre-FEC BER performance at different power levels.



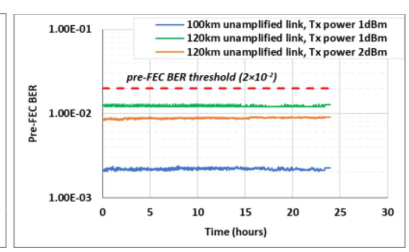


Fig. 3. 400G high power ZR+ over 310km ROADM based network link (a) long term pre-FEC BER performance and (b) optical spectrum at 75GHz and 61GHz spacing

Fig. 4 Performance over unamplified dark fiber link of 100km and 120km

Next, we show performance of 400G high power ZR+ over the 310km ROADM based network link with flexible grid WSS filters, where a spectral slot of 300GHz at center frequency 193.1THz was configured to accommodate 400G high power ZR+ wavelengths, additional spectral slots of 75GHz were configured at 192.8, 192.5, 193.4 and 193.7THz for other optical channels with output power of ~ -2dBm, typical for optical transponders. Two 400G high power ZR+ channels (75GHz spacing), with transmitter power set to similar level, are multiplexed together with these optical channels, which are then added onto the link via the WSS filter (Fig.1). Fig. 3a inset shows an optical spectrum of the combined WDM signal, where high power ZR+ wavelengths are compatible to wavelength signals from optical transponders. We investigated performance of 400G high power ZR+ WDM channels at different spacings with the channel power set to 3.8dBm. Error free performance was measured for spacings as narrow as 61GHz. Fig. 3b shows a close-up optical spectrum of the high power ZR+ channels at 75GHz spacing (193.1 and 193.175THz) and 61GHz spacing when the channels are tuned to 193.107 and 193.168THz respectively, where we see increased spectral overlapping at 61GHz spacing compared with 75GHz spacing. Fig. 3a shows stable error free performance measured over 24 hours, the two high power 400G ZR+ channels have similar performance with pre-FEC BER of ~2.1×10^{-3} at 75GHz spacing and ~3.1×10^{-3} at 61GHz spacing, well below the error free threshold showing robust performance with potential for improved spectral efficiency over standard 75GHz spacing.

For unamplified dark fiber link, in Fig. 4 we show performance of 400G high power ZR+ over different fiber length. With transmitter power set to 1dBm, for 100km dark fiber with total 19.6dB loss, error free performance was measured with pre-FEC BER of ~2.2×10^{-3} and received signal power of around -18.6dBm giving ~5.7dB loss margin compared with the measured received signal power threshold for error free performance. For 120km dark fiber with total loss of 23.84dB, error free performance was measured with pre-FEC BER of ~1.2×10^{-2} and ~1.4dB loss margin. When transmitter power increased to 2dBm, pre-FEC BER performance improved to ~8.5×10^{-3} increasing loss margin to ~2.4dB. Compared with 400G ZR/ZR+ with low transmitter output power [5], high power ZR+ has significantly increased link loss budget enabling longer reach over dark fiber. In addition, we have verified end-to-end error free performance across the virtual routers with 400GE traffic generated from 400GE testers using both random and fixed frame configurations. Fig. 5 shows Grafana dashboard of telemetry data for output data rate over a 24 hour period measured at the high power ZR+ network interfaces, achieving data throughput of over 383.5Gb/s for random frame configuration with 99% utilization. Key optical parameters are also exported from streaming telemetry, Fig. 6 shows pre-FEC BER measurement in a 24 hour period for high power ZR+ wavelength over 310km WDM link together with module information of the high power ZR+ network interface.

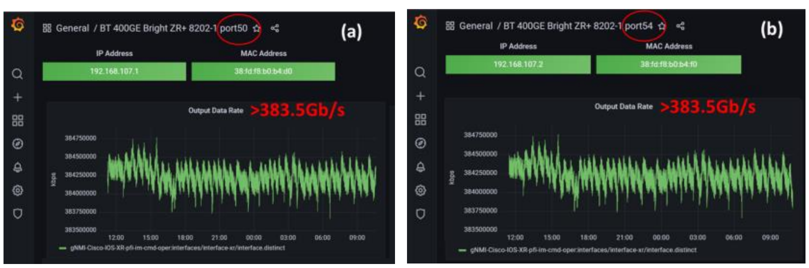


Fig. 5. End-to-end error free performance for 400G high power ZR+ IP over WDM: output data rate at (a) port 50 and (b) port 54 high power ZR+ network interface

Fig. 6 Streaming telemetry result for pre-FEC BER of 400G high power ZR+ signal

4. Conclusions

We report on successful demonstration of emerging 400G high power ZR+ for IP over WDM applications in key network scenarios. 400G high power ZR+ signals have shown long term error free performance over 310km in both point to point WDM system and ROADM based network link with large optical margin for further extended reach. Stable error free performance was measured for high power ZR+ WDM wavelengths at spacings as narrow as 61GHz demonstrating robust performance with potential for spectral efficiency improvement over standard 75GHz spacing. Error free operation over unamplified dark fiber link up to 120km has been achieved with good margin. End-to-end error free performance was verified with 400GE traffic, we have also demonstrated streaming telemetry for monitoring on optical performance and data throughput in 400G high power ZR+ IP over WDM.

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6. References

[1] K. Roberts *et. al.*, Journal of Optical Communications and Networking, vol. 9, no. 4, pp. C12 - C24, April 2017
[2] Y. R. Zhou *et. al.*, Journal of Lightwave Technology, vol. 41. no. 3, pp. 957 - 967, February 2023
[3] F. Pittalà *et. al*., IEEE Photonics Technology Letters, vol. 34, no. 3, pp. 157 – 160, February 2022
[4] Y. Loussouarn *et. al*., Journal of Lightwave Technology, vol. 37, no. 2, pp. 538 – 547, January 2019
[5] Implementation agreement 400ZR: https://www.oiforum.com/wp-content/uploads/OIF-400ZR-01.0_reduced2.pdf, 10 March 2020
[6] OpenZR+ specification v.3.0: https://openzrplus.org/documents/, 12 September 2023
[7] Cisco 400G QSFP-DD High-Power (Bright) optical module data sheet: https://www.cisco.com/c/en/us/products/collateral/interfaces-modules/transceiver-modules/400g-qsfp-dd-high-power-optical-module-ds.pdf
[8] https://github.com/influxdata/telegraf