Multivendor 100G Coherent DWDM Line-Side Interoperability

Juniper-Telefonica Joint Field Trial

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Executive Summary

The ever-increasing demand for network capacity is driving the deployment of both multi-terabit core routers as well as terabits of dense wavelength-division multiplexing (DWDM) transport capacity in today's networks. At the transport layer, the use of coherent detection and digital signal processing (DSP) in 100G DWDM transceivers has revolutionized optical transport by vastly simplifying the design, deployment, and performance monitoring of transport networks, quickly establishing 100G coherent DWDM transceivers as the technology of choice for metro, regional, long-haul, and submarine transport networks. As a result, 100G coherent DWDM transceivers have evolved from their initial deployments[1] in 2009 and 2010 into a mature technology with more than 200,000 ports deployed[2] worldwide in 2015.

This white paper describes the results of a field trial in the Telefonica International network between Boca Raton and Jacksonville, Florida. The DWDM interfaces are integrated on Juniper Networks and Cisco routers, with the goal of demonstrating how 100G coherent DWDM line-side interoperability and standardized pluggable DWDM coherent optics improve the flexibility of next-generation packet-optical transport networks.

Introduction

Today's networks rely on large numbers of standards and implementation agreements to ensure multivendor interoperability at the optical transport network (OTN), Ethernet, and IP/MPLS network layers. However, at the optical transport layer, which is where 100G coherent DWDM transceivers reside, proprietary implementations have dominated. The first generation of 100G coherent DWDM transceivers required extensive research and development in both optical and digital signal processing technologies. Therefore, the use of discrete performance-optimized optical components, best-in-class proprietary DSP algorithms, and proprietary forward error correction (FEC) codes were initially critically important to gain a competitive advantage in 100G deployments. Now that 100G dual polarization-quadrature phase shift keying (DP-QPSK) is a mature technology, it is highly preferable that DWDM transceivers from different system vendors be interoperable at the optical transport layer to simplify the deployment of multivendor networks. Line-side interoperability requires the use of a standardized FEC code as well as standardized OTN framing and common DP-QPSK symbol mapping.

100G Line-Side Interoperability

For a variety of reasons, most transport networks have DWDM transceivers from different vendors—legacy installations, technology redundancy, different optical performance requirements (metro versus long haul), or simply for commercial reasons. Without line-side interoperability, each 100G coherent DWDM transceiver needs to be bookended by an identical DWDM transceiver, significantly reducing flexibility in network deployments. Therefore, line-side interoperability between 100G coherent DWDM transceivers from different vendors is tremendously beneficial for network simplicity and optimization.

Line-side interoperability is particularly relevant when the 100G coherent DWDM transceivers are integrated into the routing platforms. IP-optical integration simplifies network deployments by reducing budget, space, and power consumption while enabling faster service turn-up and more capabilities for multilayer optimization. The tighter integration between the network's IP/MPLS and DWDM transport layers is therefore becoming ever more important in next-generation network architectures. Since multivendor interoperability is common for both IP/MPLS network protocols as well as Ethernet client interfaces, the same expectation is set for DWDM interfaces integrated on router line cards.

The 100G coherent DWDM line cards for Juniper Networks® MX Series 3D Universal Edge Routers support a variety of FEC modes, ensuring maximum flexibility in different network deployments. For multivendor deployments, interoperable FEC modes are supported based on generic FEC (GFEC) and the high-gain FEC (HG-FEC) codes. In addition, a proprietary FEC mode with soft-decision decoding is supported, enabling maximum optical performance and (ultra) long-haul transmission.

GFEC is a Reed-Solomon FEC code standardized by the ITU-T in G.975. Included in the ITU-T G.709 standardized OTU4 framing standard, GFEC is widely supported across transport platforms[3]. Compared with today's state-of-the-art FEC performance, GFEC's 6.2 dB coding gain is fairly moderate, limiting its applicability to metro networks at 100G bit rates. However, since it is widely supported across many transport platforms, it has the unique ability to enable line-side interoperability across most platforms in the industry.

HG-FEC is specifically designed to preserve the standardized OTU4 frame for 100GbE client signals with a bit rate of 111.81 Gbps, but it provides a higher coding gain through an advanced code structure and iterative decoding. The HG-FEC code is based on a Bose-Chaudhuri-Hocquenghem (BCH) code with a rate R = 239/255 (6.7% overhead). The iterative hard-decision decoding algorithm results in a pre-FEC BER threshold of 4.6e-3 for a post-FEC BER of 1e-15, which translates into a 9.4 dB NCG[4]. The HG-FEC code, therefore, provides a significantly higher NCG compared to GFEC, enabling 100G line-side interoperability over regional and long-haul transmission distances of more than 1000 km.

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[1] G. Wellbrock and T.J. Xia, "The road to 100G deployment" IEEE Communications Magazine, p. S14-S18 (2010)

[2] Networking Ports: 1G, 2.5G, 10G, 40G, 100G Market Tracker, 2nd-Edition 2015, Infonetics Research (2015)

[3] ITU-T Rec. G.709, "Interfaces for the optical transport network" (2012)

Since HG-FEC mode uses a hard-decision decoder, it is only moderately complex to implement and can be integrated into the DSP ASIC, a separate OTN famer ASIC, or implemented in an FPGA. This implementation flexibility makes the HG-FEC code ideally suited for line-side interoperability across different 100G transport platforms. As a result, HG-FEC has become a de facto industry standard that is implemented in 100G DWDM transceivers and IPoDWDM line cards from multiple system vendors.

The soft-decision FEC (SD-FEC) code supported on the 100G DWDM interface for MX Series routers is based on a Turbo Product Code (TPC) with 15% overhead and a theoretical 10.8 dB coding gain. A soft-decision decoder architecture optimizes the code to maximize optical performance, making it particularly well suited for long-haul deployments supporting transmission distances of 2000 km or more in transport networks.

100G Coherent Pluggable Interfaces

The 100G DWDM line cards used in this field trial are equipped with CFP2-ACO-pluggable DWDM coherent optics. The analog coherent optics (ACO) architecture, which decouples the optical and electronic functionality of a 100G coherent DWDM interface, is very promising. The CFP2-ACO pluggable form factor integrates all optical functionality required for a 100G coherent transceiver into the CFP2 pluggable form factor, whereas the DSP ASIC that implements signal equalization, forward error correction, and framing is still placed on the line card. ACO therefore refers to the high-speed analog interface between the CFP2-ACO pluggable form factor and the DSP ASIC on the line card.

Decoupling the optical and electronic functions of the 100G coherent DWDM interface allows CFP2-ACO manufacturers to focus on state-of-the-art optical integration and miniaturization, which is required to build a full 100G coherent optical front end within the space and power constraints of a CFP2 form factor. System vendors building 100G coherent DWDM line cards can instead focus on the required high-speed electronics design, vastly simplifying the design, manufacturing, and testing of the line card. This disaggregated architecture also improves interoperability since the same pluggable coherent optics implementation can be used across different transport platforms.

The ACO architecture has been defined in an implementation agreement by the Optical Internetworking Forum (OIF) , ensuring broad industry support. CFP2-ACO pluggable interfaces, available from many of the major optical transceiver vendors worldwide, can be built using different optical integration technologies, including Indium Phosphate (InP) or Silicon Photonics (SiP), ensuring a healthy ecosystem with significant investment in optical integration to further develop and enhance the pluggable optics architecture. Although originally conceived for 100G metro solutions, the ACO architecture is proven to enable excellent optical performance for 100G data rates, making it suitable for deployment in metro, regional, and even long-haul transport networks.

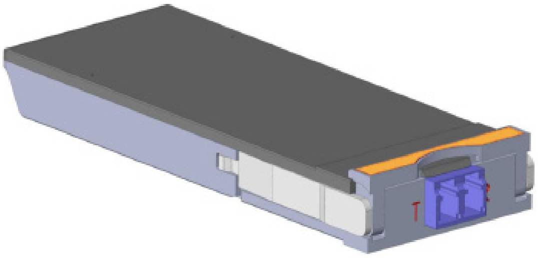

Figure 1: CFP2-ACO pluggable DWDM optics

Field Trial Topology

The 100G coherent DWDM field trial used two Juniper Networks MX2020 3D Universal Edge Router devices deployed in Boca Raton and Jacksonville, Florida. The 20-slot MX2020, Juniper's flagship router for provider edge networks, is widely used in edge, peering, and core network deployments. The MX2020 chassis scales up to 32 terabit full-duplex traffic throughput, making it ideal for next-generation network architectures. A Cisco ASR 9904 router, also located in Boca Raton, is used during the field trial for the multivendor line-side interoperability test cases. ASR 9904 is part of the ASR 9900 Series, representing Cisco's paradigm in edge and core routing.

The DWDM transport link used during the field trial is part of Telefonica's network running between Boca Raton and Jacksonville, with a one-way distance of approximately 515 km. The link consists of six fiber spans, with five in-line EDFAs, one intermediate ROADM, and two ROADMs with DWDM multiplexers at the endpoints. The transmission link consists of 470 km of Large Effective Area Fiber (LEAF, G.655) as well as a single 45 km fiber span of standard single-mode fiber (SSMF, G.652). The link is dispersion uncompensated—hence the accumulated chromatic dispersion is compensated through digital signal processing in the receiver, delivering the best optical performance for 100G coherent

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[4] B.P. Smith et al., "Staircase Codes: FEC for 100 Gb/s OTN," J. Lightwave Technol., Vol. 30, no. 1, p. 110 (2012)

[5] OIF Implementation agreement for CFP2 Analogue Coherent Optics Module, OIF-CFP2-ACO-01.0 (2016)

DWDM transceivers. The 100G DWDM channel is transported as alien wavelength over a third-party DWDM platform, simultaneously carrying both production traffic and the channel-under-test during the field trial. The 100G DWDM channel-under-test is located at 1561.42 nm, where an appropriate guard-band ensured there was no interference between co-propagating DWDM channels.

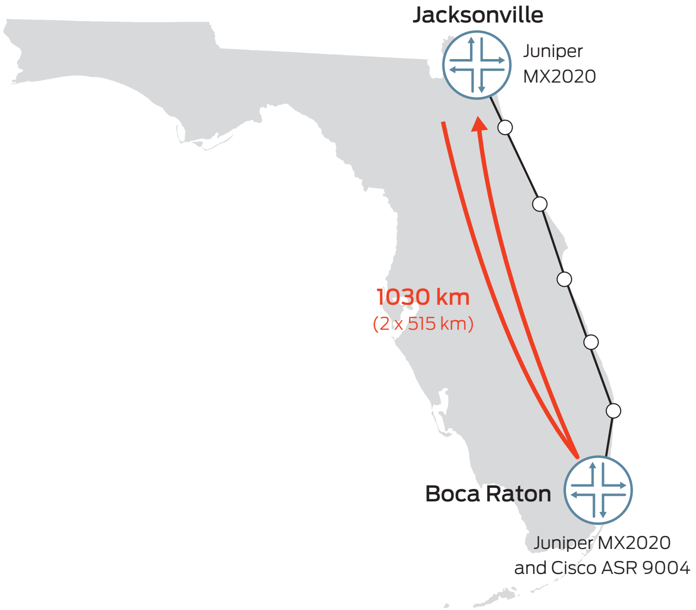

Figure 2: The transport link used during the field trial—515 km one-way between Boca Raton and Jacksonville and 1030 km in total for the loopback

Test Case 1: Boca Raton and Jacksonville

The first test scenario consists of 100G unidirectional transport between the two MX2020 routers, each using one 100G coherent DWDM line card. In this first test scenario, both the optical performance in the SD-FEC and HG-FEC modes are tested during an overnight soak test to ensure long-term stability. The measured pre-FEC BER values are shown in Figure 4.

The minimum, maximum, and average pre-FEC BER is measured throughout the entire soak test. The minimum and maximum values represent the one-second lowest, respectively highest, pre-FEC BER interval during each 15-minute period. Comparing the average and maximum pre-FEC BER reveals any potential error bursts or transients. As Figure 4 shows, the small difference between the two indicates that the transport link was stable throughout the 24-hour soak test.

In HG-FEC mode, an average pre-FEC BER of 4.7e-6 (12.9 dBQ) is measured, whereas the average pre-FEC BER in SD-FEC mode is 1.3e-5 (12.5 dBQ). This 0.4 dB difference in measured Q-factor is the result of the higher bit rate in SD-FEC mode (120.58 Gbps) compared to HG-FEC mode (111.81 Gbps), which slightly increases the measured pre-FEC BER. Changing the bit rate from 111.81 Gbps to 120.58 Gbps would theoretically result in a 0.33 dB difference, which is close to the measured 0.4 dB performance difference.

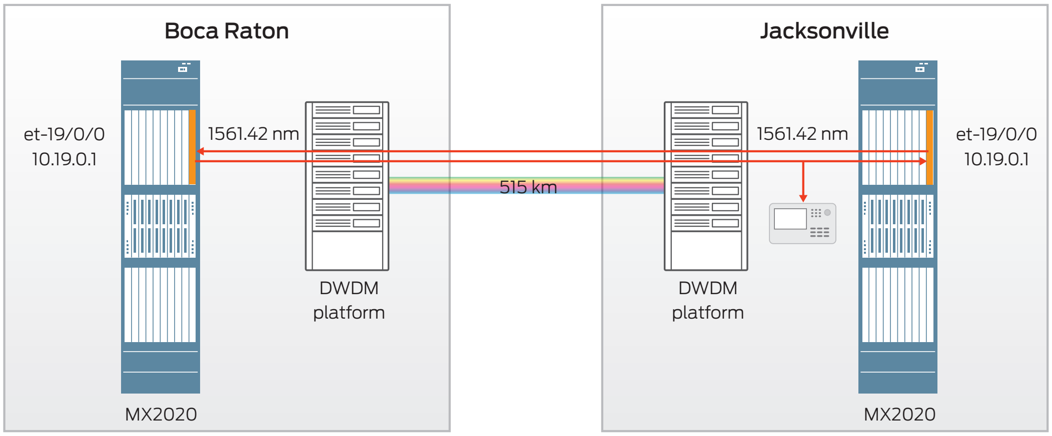

Figure 3: Unidirectional transmission test between Boca Raton and Jacksonville over a total distance of 515 km

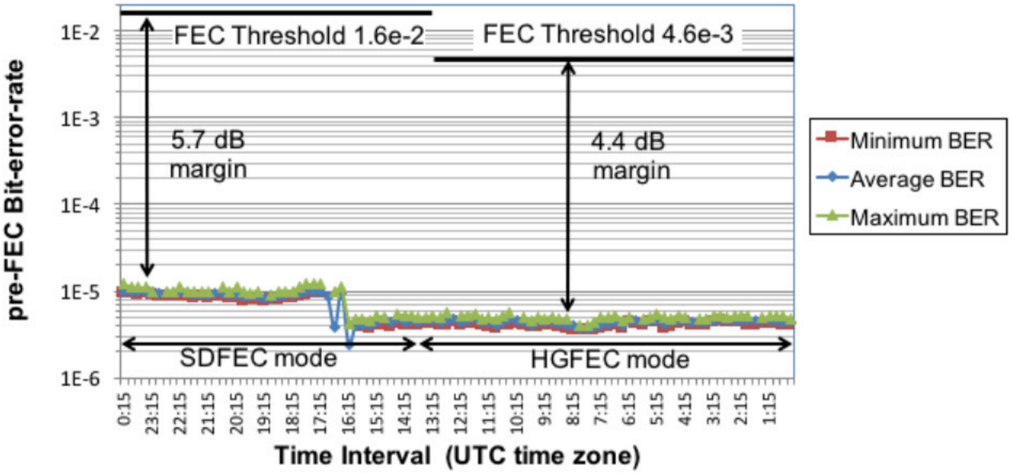

Figure 4: 24-hour soak test of the link between Boca Raton (Tx) and Jacksonville (Rx)—the 100G DWDM interfaces are switched from HG-FEC to SD-FEC mode during the test

The SD-FEC mode has a higher system margin despite the somewhat higher pre-FEC BER measured. Based on the difference between maximum pre-FEC BER and the FEC threshold, the system margin is 5.8 dB and 4.5 dB for SD-FEC and HG-FEC, respectively. The difference of 1.3 dB in system margin follows from the 0.4 dB difference in measured pre-FEC BER and the 1.7 dB difference in absolute coding gain between the two FEC modes. This aligns with the expected net coding gain difference of 1.4 dB.

Figure 5 shows the measured optical performance during the same soak test, but now with the transmitter in Jacksonville and the receiver in Boca Raton. Transmission performance is very similar, with a worst-case 4.5 dB margin in HG-FEC mode and a 5.8 dB margin in SD-FEC mode. Both directions therefore show stable optical performance, with significant system margin over 515 km in both SD-FEC and HG-FEC modes.

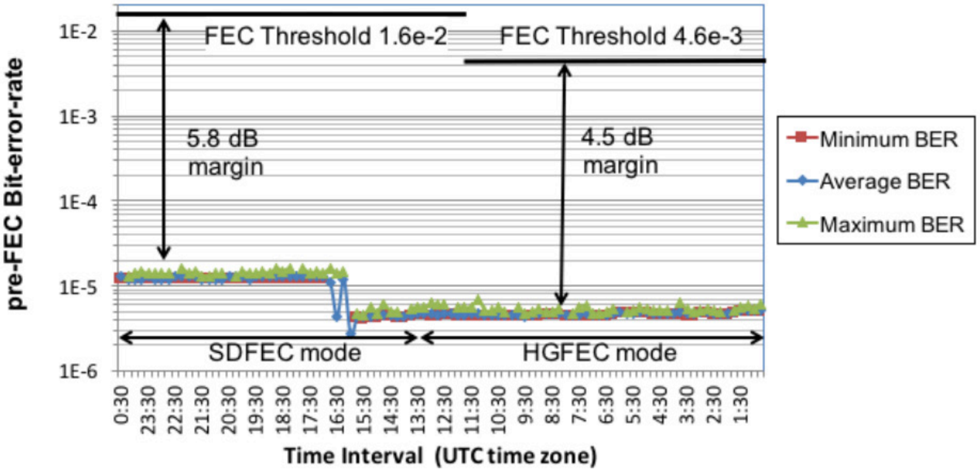

Figure 5: 24-hour soak test of the link between Jacksonville (Tx) and Boca Raton (Rx)—the 100G DWDM interfaces are switched from HG-FEC to SD-FEC during the test

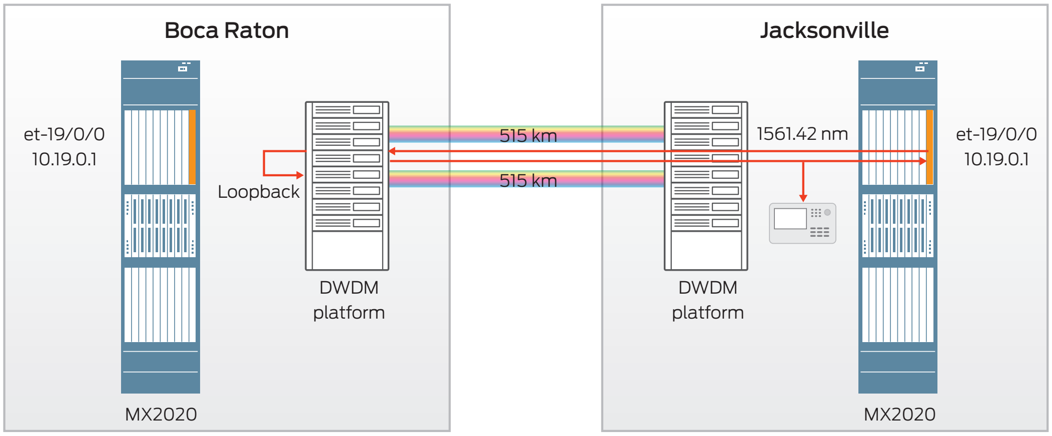

Figure 6: Boca Raton to Jacksonville with loopback in Jacksonville—both transmitter and receiver are in Boca Raton and the total transmission distance is 1030 km

Test Case 2: Boca Raton and Jacksonville Loopback

In the second test case, the total transmission distance is doubled to 1030 km by switching to optical loopback on the ROADM in Boca Raton and terminating the wavelength on the same MX2020 line card in Jacksonville.

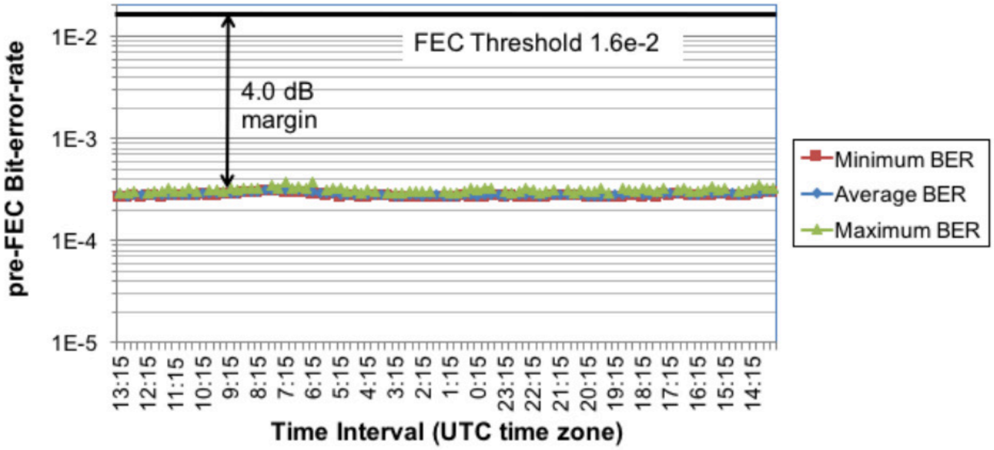

Figure 7: 24-hour soak test of the link between Jacksonville and Boca Raton with loopback in Jacksonville—the interfaces are configured to SD-FEC mode

The soak test over the loopback link confirms long-term performance is stable, with an average measured pre-FEC BER of 2.8e-4 and a worst-case system measured pre-FEC BER of 3.7e 4 in SD-FEC mode (see Figure 7). The worst-case system margin with respect to the SD-FEC threshold is therefore equal to 4.0 dB, showing stable long-term optical performance with an excellent operating margin over 1030 km.

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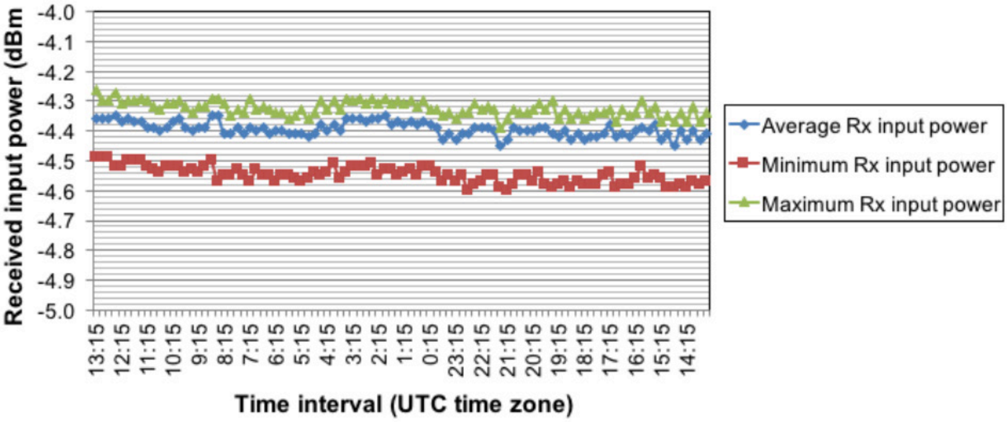

Figure 8: Received optical power during a 24-hour soak test on the looped-back Boca Raton to Jacksonville link with both transmitter and receiver in Jacksonville

The optical power incident on the receiver is also a parameter that can be used to monitor the stability of the transmission link. The 100G coherent DWDM line cards allow for a very granular measurement of the received optical power, including minimum, average, and maximum power measurements. Figure 8 shows the measured received input power for transmission over 1030 km on the transport link between Boca Raton and Jacksonville, with loopback in Jacksonville. The measurements indicate less than 0.4 dB in power fluctuations in 1-second time interval granularity over the entire 24-hour soak window when comparing the minimum and maximum received optical power. This indicates extremely stable optical power control of the transmission link, which is well matched by the stable pre-FEC BER performance measured during the test window.

Test Case 3: Juniper-Cisco Line-Side Interoperability

In the third test case, the test setup is switched from Juniper routers on both endpoints to a line-side interoperability test scenario between a Juniper Networks MX2020 3D Universal Edge Router and Cisco ASR 9004 router. Both devices are located in Boca Raton, and the same 1030 km transport link from Boca Raton to Jacksonville with loopback in Jacksonville is used.

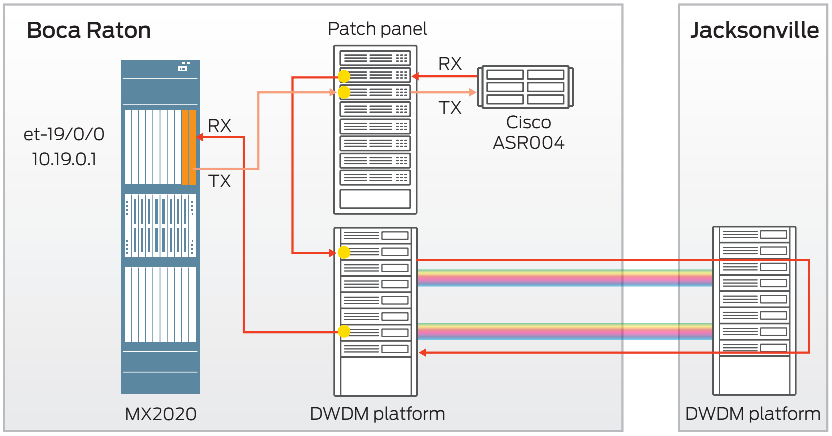

Figure 9: Boca Raton to Jacksonville with loopback over 1030 km and connecting a Cisco 100G DWDM transmitter (in the ASR 9004) with the Juniper 100G DWDM receiver (in the MX2020)

This test case aims to demonstrate multivendor line-side interoperability for 100G coherent DWDM interfaces and show that this is feasible with an optical performance comparable to proprietary 100G DWDM interfaces. In the first test, as shown in Figure 9, the transmitter of the ASR 9004 100G DWDM line card transmits the signal over the long-haul transport link. The signal received from the transmission link is fed into the receiver on the MX2020 100G DWDM line card, which is also used to collect the optical performance monitoring statistics. The transmitter of the MX2020 IPoDWDM line card is connected back to back to the receiver on the ASR 9004 IPoDWDM line card.

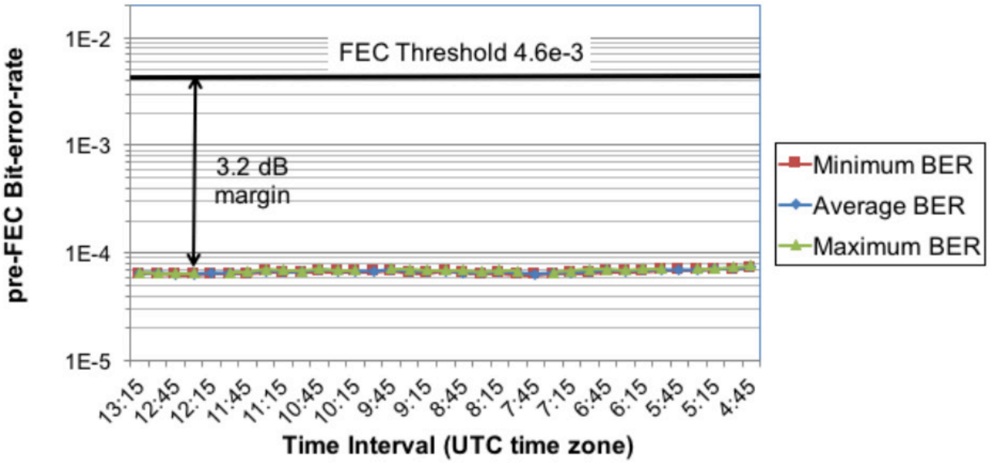

Figure 10: Soak test of the link between Jacksonville and Boca Raton with loopback in Jacksonville over 1030 km with Cisco 100G DWDM transmitter and Juniper 100G DWDM receiver

Optical performance monitoring statistics for the multivendor line-side interoperability scenario are collected during a soak test running for more than eight hours, as shown in Figure 10. The worst-case system measured pre-FEC BER during the measurement time frame was 7.6e-5, with an average pre-FEC BER of 6.7e-5. The measured pre-FEC BER translates in a worst-case system margin relative to the HG-FEC threshold of 3.2 dB. This confirms excellent optical transmission performance over 1030 km using the HG-FEC mode to enable line-side interoperability between the Juniper and Cisco 100G DWDM router line cards.

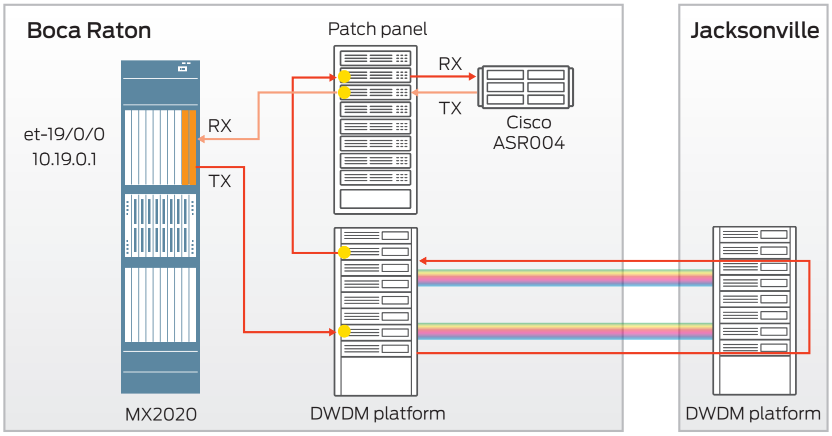

Figure 11: Soak test of the link between Jacksonville and Boca Raton with loopback in Jacksonville over 1030 km with Juniper 100G DWDM transmitter and Cisco 100G DWDM receiver

Finally, in a second test, the transmitter and receiver directions are switched, with the 100G coherent DWDM line card in the Juniper MX2020 router transmitting the signal over the long-haul DWDM link and the 100G coherent DWDM interface in the Cisco ASR 9004 receiving the signal. Optical performance monitoring statistics are collected on the Cisco ASR 9004 DWDM line card over an 18-minute period, as shown in Figure 12. The worst-case average pre-FEC BER (over two-minute time slots) is 4.1e-5, with an average pre-FEC BER measured over the 18-minute measurement period of 2.3e-5.

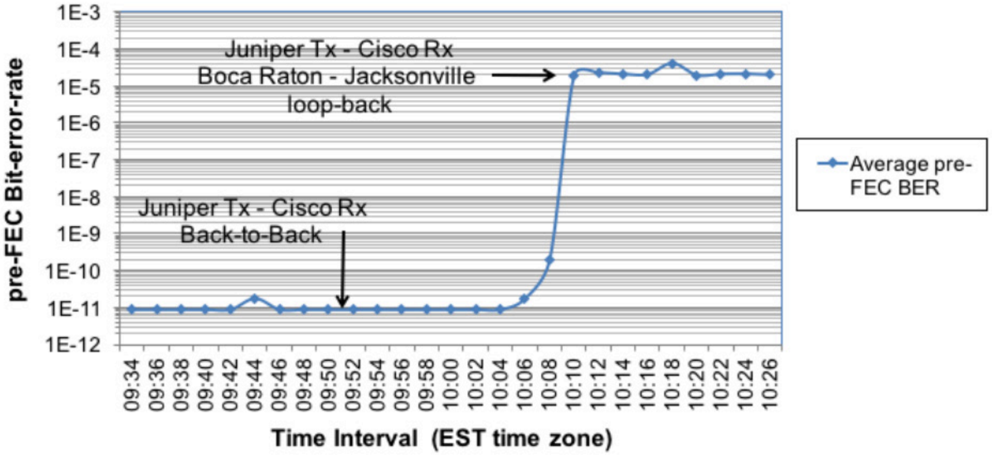

Figure 12: Soak test of the link between Jacksonville and Boca Raton with loopback in Jacksonville over 1030 km with Juniper 100G DWDM transmitter and Cisco 100G DWDM receiver

Conclusion

The field trial over 515 km between Boca Raton and Jacksonville yields a system margin in excess of 5.7 dB in SD-FEC mode and 4.4 dB in HG-FEC mode. Including loopback in Jacksonville and extending the total transmission distance to 1030 km we measured a 4 dB margin in SD-FEC mode. All measurements show excellent long-term stability with minimum performance variation during overnight soak tests.

The multivendor line-side interoperability measurements between 100G coherent DWDM router line cards on the Juniper Networks MX2020 3D Universal Edge Router and Cisco ASR 9004 show excellent optical performance. A 3.2 dB margin is measured on the Boca Raton to Jacksonville link with loopback in Jacksonville.

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