# Real-Time 1.2Tb/s Large Capacity DCI Transmission

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**Abstract:** We demonstrate real-time WDM transmissions of 39.6 Tb/s (33x1.2Tb/s) over a 172km fibre link. The transmission was accomplished without post-FEC error for >46-hours.


## 1. Introduction

The sustained and ongoing exponential growth of global cloud services drives the need for high-capacity transmission between data centers. Data centers connected by single-span links are separated by distances of 10 to 120 km without intermediate amplification. The 400ZR agreement has led to the massive deployment of multi-vendor data center interconnect (DCI) transmission at 400Gb/s over a maximum distance of 80 to 120 km [1]. Standardization discussions in OIF have been focused on 800ZR recently to support transmission speeds of 800Gb/s over the same distance [2].

Over the past few years, significant research efforts have been dedicated to improving the DCI capacity and achieving net data rates greater than 1Tb/s per wavelength. Typically, the net rate achieved in these recent records uses offline processing and is based on the estimated generalized mutual information (GMI) derived from the received constellation [3-4], or by performing forward error correction (FEC) decoding using a short length of captured data [5-8]. However, the Tb/s coherent transceiver is susceptible to various impairments, including clock jitter, even in back-to-back configurations, as well as to fast-behaviour nonlinear interference noise after transmission. These impairments impact on post-FEC error over a long measurement time. For instance, a single uncorrectable FEC block event during overnight measurement, when the bit error rate (BER) is below the FEC threshold, cannot be detected in offline processing. Additionally, stimulated Raman scattering (SRS) causes a large OSNR variation over the entire C-band. Short-wavelength channels usually have poorer performance due to lower OSNR and higher nonlinearity. Consequently, long-term real-time wavelength-division multiplexing (WDM) transmission measurements are of great importance.

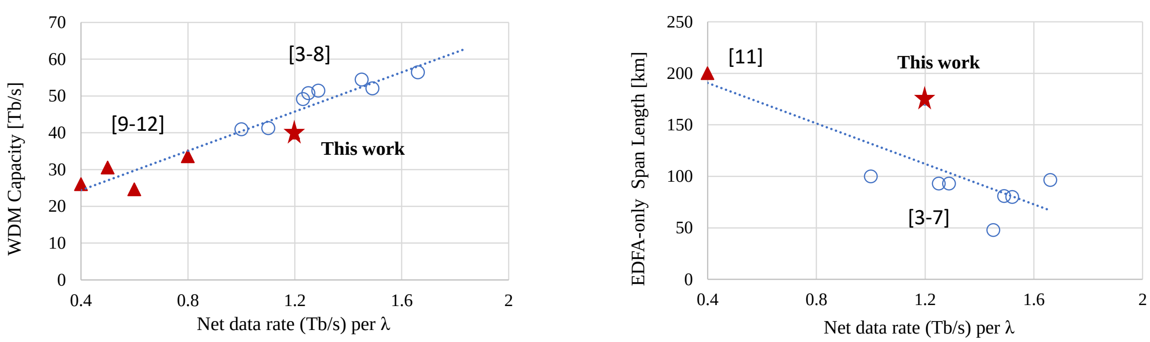


Fig.1. WDM capacity and EDFA-only single-span length record with offline processing (blue circle) and real-time (red triangle) measurement

Fig.1 summarizes the records of WDM capacity and EDFA-only single-span distance using both offline processing and real-time experiments, including the work presented in this paper. In this study, we demonstrate real-time WDM transmissions of 39.6 Tb/s (33x1.2Tb/s) over a 172km fibre link. To the best of our knowledge, this is the longest span length achieved for a fully loaded C-band at 1.2Tb/s. This work showcases a potential path toward fully loaded C-band 1.6Tb/s WDM transmissions over typical ZR distances for DCI applications.

## 2. Real-time 1.2 Tb/s coherent transceiver

The 1.2Tb/s WDM transmission experiment was carried out with a pluggable coherent transceiver consisting of a single tuneable laser, a single substrate containing a 3D stacking of the Silicon Photonics (SiPh) integrated circuit, drivers, transimpedance amplifiers (TIA), and a 5 nm CMOS ASIC with four high-speed analog-digital converters (ADC) and digital-analog converters (DAC). The coherent transceiver also includes a transmitter (TX) EDFA followed by a tuneable optical filter, providing > 3 dBm of TX output power over the entire C-band. The signal is generated using dual-polarization probabilistic constellation shaping (PCS) based on 64QAM. PCS offers a high

OSNR sensitivity closer to the Shannon limit and the flexibility to adapt the entropy to the channel SNR. The entropy of PCS 64QAM is optimized at 5.27 bits per symbol, resulting in a net rate of 1.2Tb/s at 138 GBd.

In DCI applications, the system performance is largely determined by the intrinsic signal-to-noise (SNR) of the transceiver. The transceiver SNR is affected by various factors, including DSP quantization noise, thermal noise, nonlinear distortion of the analog components, and ASE noise from the TX EDFA. At high baud rate, the transceiver SNR is significantly limited by the TX optical signal-to-noise ratio (OSNR). Achieving a high TX OSNR requires a large swing of the driver signal into the SiPh modulator to minimize modulation dependent loss, but this also leads to significant nonlinear distortion of the driver. To address this, we implement a complete digital equalization by incorporating both a linear pre-equalization filter and nonlinear pre-distortions, as illustrated in Fig. 2. The linear pre-equalization filter improves the signal bandwidth to exceed 70GHz and compensates for frequency-dependent group delay. The nonlinear pre-distortion mitigates undesired component response resulting from the large swing signal, which exhibits a high peak-to-average power ratio due to the pre-equalization of the PCS signal.

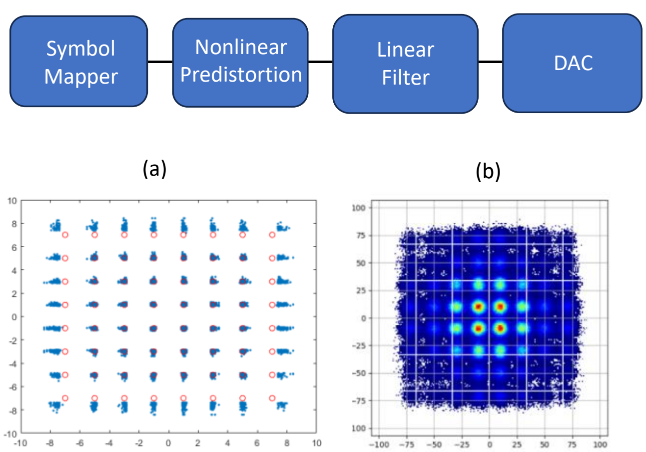


Fig.2. (a) TX nonlinear predistortions (blue dots) from default symbols (red circles) (b) RX recovered constellation

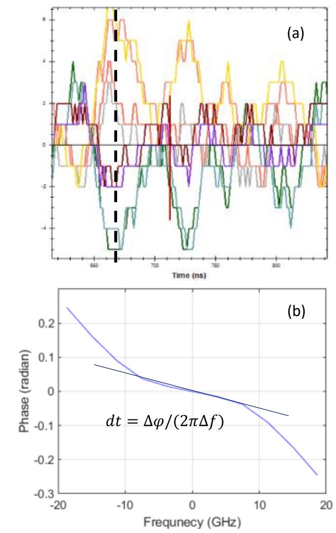


Fig.3. Real-time record of equalizer taps and their phase spectrum (b) captured at the time indicated by the dashed line in (a).

The Tb/s coherent transceiver, which operates at a baud rate of >100GBd and has a high spectral efficiency, is sensitive to nonlinear interference noise after transmission, and can cause uncorrectable FEC frames at low BER. To address this, a nonlinear equalization technique is employed in the receiver for WDM transmission, helping to reduce the impact of nonlinear interference noise. Additionally, an adaptive equalizer is used to compensate for residual clock jitter. Fig. 3a illustrates that the taps of the equalizer are dynamically adjusted. In Fig. 3b, a snapshot of these taps reveals the characteristics of an interpolation filter used to compensate a residual time offset determined by $\Delta\varphi/(2\pi\Delta f)$ near the DC frequency.

## 3. Real-time 1.2Tb/s WDM Transmission of 39.6 Tb/s over 172km Fiber Span

Fig.4 (a) illustrates the experimental setup for the 1.2Tb/s WDM transmission link. The transmitters consist of one loading and one measurement path. In the measurement path, one 1.2Tb/s channel and two adjacent 400Gb/s channels, separated by 125GHz spacing, are combined. The loading path consists of a broadband ASE source that is notch-filtered by a 50GHz-channelized wavelength selective switch (WSS) filter. The combined WDM channels are then amplified by an EDFA with 23dBm output power and 39.6nm bandwidth and transmitted over the fibre link with equal launch power. The transmission link comprises a total of 172 km fibre with an $A_{eff}$ of 85 μm$^2$ and an average attenuation of 0.1485dB/km at 1550nm. The span loss of the link, including splicing and connectors, is 26.0dB. A second EDFA is used to amplify the WDM signals before they are sent to a demultiplexer (DeMux). The selected channel from the DeMux is then fed back to the 1.2Tb/s receiver. We emphasize the group of three channels and measure the performance of the 1.2Tb/s channel. Fig. 4(b) shows the $Q^2$ margin of 1.2Tb/s channel as a function of OSNR after the 172km transmission. The optimal OSNR values are approximately 36~37dB/0.1nm for middle and long wavelength channels at 1550.12nm and 1564.68nm, and 34dB/0.1nm for the short wavelength channel at 1529.94nm, respectively. Under optimal launch power condition, a minimum $Q^2$-margin of >0.34dB can be obtained.

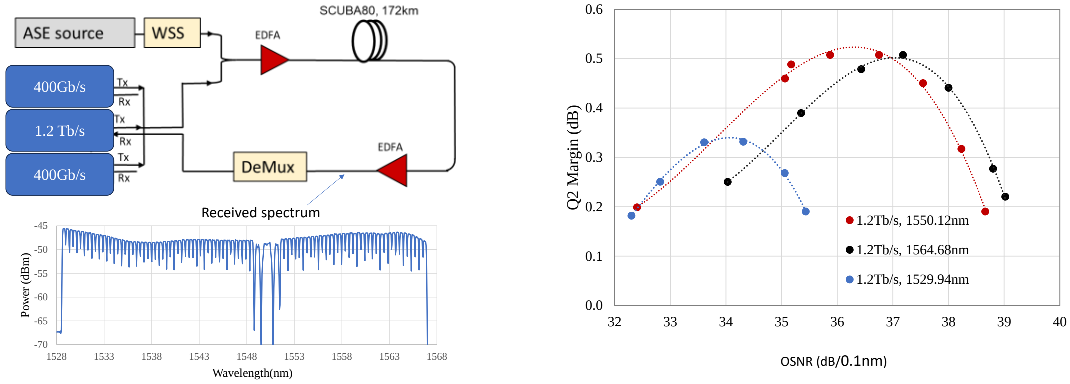


Fig.4 Experimental set-up for 1.2Tb/s WDM transmission over 1722km span and 1.2 Tb/s performance vs OSNR

Fig. 5 (a) presents the results of the 1.2Tb/s capacity experiment with flat launch power. The group consisting of the 1.2Tb/s channel and two adjacent 400Gb/s channels is translated in 150GHz steps across the C-band. The average OSNR across the 33 channels is 35.0dB/0.1nm with a variation of 3.3dB. The large variation in OSNR is primarily caused by relative strong stimulated Raman scattering. The average $Q^2$-margin ranges from 0.24dB to 0.56 dB across the entire C-band. The poorer performance in $Q^2$-margin observed in the short wavelength channels is due to both relatively low OSNR and high nonlinear impact. To access the reliability in practical deployable systems, a long-term performance measurement of 1.2Tb/s channel at 1550.12nm is conducted after WDM transmission over 172km span. The real-time BER measurements are collected at 1-second intervals, and all transmitted data are successfully decoded by FEC without error for more than 46 hours.

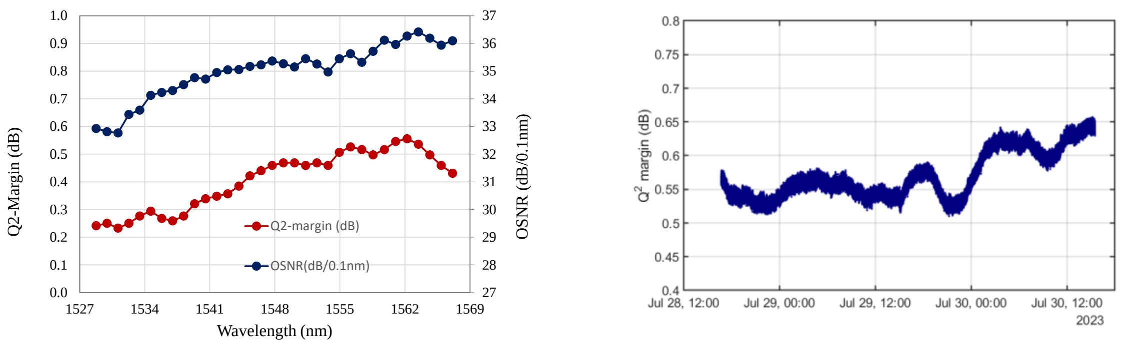


Fig.5 (a) 33x1.2Tb/s capacity study after 172km and (b) $Q^2$-margin (error-free after FEC) for more than 46 hours of measurement

## 4. Conclusion

We discussed the value of real-time large capacity experiment and some DSP techniques for Tb/s DCI applications. We presented the first demonstration of real-time 1.2Tb/s WDM transmissions over 172km fibre span, resulting total capacity of 39.6Tb/s.

## 5. References


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