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Regular Articles

Inter-data center 28 Gbaud 4-PAM transmission over 240 km standard single mode fiber

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ABSTRACT

We report on achieving 28 Gbaud 4-PAM transmission with post-equalization over a 240 km SSMF link without re-engineering the transmission link design. The results demonstrate the prospect of re-using conventional links for inter data center connections.

1. Introduction

As the bandwidth demands between data centers continue to increase, deployment of larger scale data-center switching fabrics is driving strong demand beyond 10GbE, 40GbE, and 100GbE connectivity, towards 400GbE in a foreseeable future. Another development is the choice of modulation formats such as 4-level pulse amplitude modulation (4-PAM) for the next generation of 200GbE and 400GbE standards such as IEEE P802.3bs [1].

The scenario seen in Fig. 1 depicts two data centers that are interconnected using a long distance, high bit-rate link. With such a scheme service providers would desire to generate a high-speed 4-PAM signal in one rack in data center A and seamlessly transmit this signal though a long span of fiber, uninterrupted, to a rack in data center B. Service providers managing data center interconnects, experience a gap between the capabilities of client-side and long-haul optics, resulting from the scaling trends in the data center business [2]. Long-haul optics have both the capacity and reach needed for data center interconnects, but most long-haul technologies are considered to be too expensive and complex. Client-side optics is more affordable but do not offer the needed reach and capacity for data center interconnects [3].

In scenarios supporting 240 km, the deployment of fiber links follows the traditional approach as in metro networks of Single Mode Fiber (SMF) spans of 80 km, followed by a matching Dispersion Compensating Fiber (DCF) block. As these designs are fairly static and given the evolving nature of communication technologies in terms of bitrate and modulation format of choice, it is keystone to ensure backward compatibility of different modulation formats over the same inter data center link, notably Non-Return to Zero (NRZ) and PAM.

In this paper, we experimentally demonstrate transmission of 28 Gbaud 4-PAM over 240 km Standard SMF (SSMF) using a simple Intensity Modulation and Direct Detection (IM-DD) modulation scheme. The transmission distance is achieved by using an Electro-absorption Modulated Laser (EML), which is an integration of a Distributed Feed-Back (DFB) laser and an Electro-Absorption Modulator(EAM) on the same chip, it has a low coast and small footprint. We implement post-equalization and keep the conventional transmission link design unchanged. Recent research have proven higher data speeds using 4-PAM to be possible, but at a much shorter transmission distance, for example 214 Gbit/s over 10 km as in [4]. In cases where 4-PAM modulation have been used for longer transmission distances (100–400 km) the symbol rates have been lowered, for example to 20 Gbaud as in [5]. In between these two cases we find demonstrations of 128 Gbit/s 4-PAM with transmission distances up to 80 km [6]. The speed and distance is enabled by the use of an external dual drive Mach–Zehnder modulator and dispersion pre-compensation. Also a demonstration of 4-PAM done with an EML at a data rate of 58 Gbit/s over 60 km of SSMF has been proven in [7]. The transmission wavelength of 1300 nm, along with the use of an Avalanch Photo Diode (APD) insures zero fiber dispersion and enough receiver power to not use optical amplification. For low cost demonstrations, a combination of lower symbol rates and special Vertical Cavity Surface Emitting Laser (VCSEL) arrays have been developed to transmit the 4-PAM on multiple wavelengths as in [8].

2. Experiment

Fig. 2 shows the experimental setup. The generation of the 28 Gbaud modulation format, started with two NRZ signals at 28 Gbit/s generated by an Arbitrary Waveform Generator (AWG) transmitting two Pesudo Random Binary Sequences with length 2^{15} (PRBS15) that

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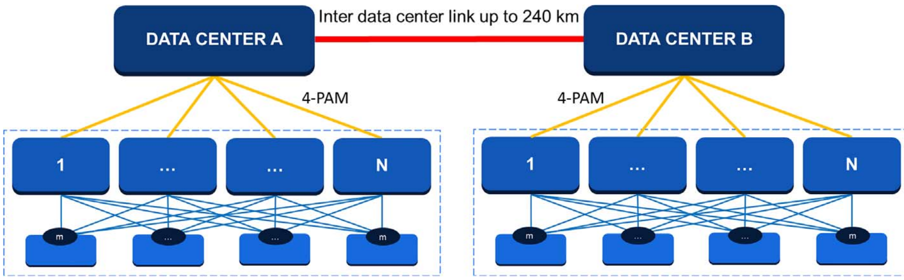

Fig. 1. Scenario for 240 km transmission in inter data center links. Each data center contains 1 to N racks with m sub-racks.

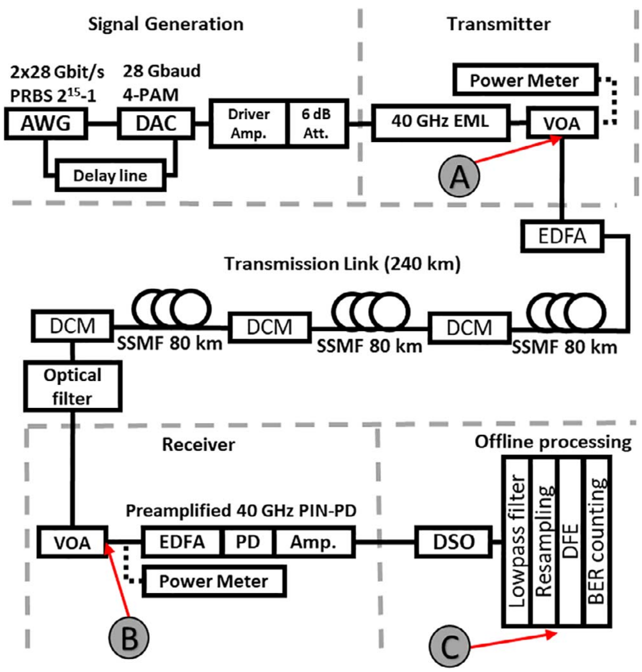

Fig. 2. Setup for 28 Gbaud 4-PAM transmission over 240 km SMF for inter data center connectivity.

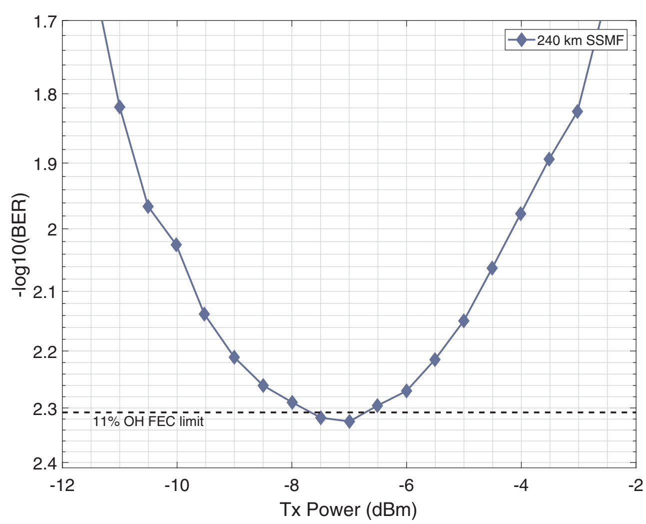

Fig. 3. BER as function of transmitter power (Tx power) for 240 km SSMF transmission.

were uncorrelated to each other. The two NRZ signals were bit synchronized with an electrical delay line at the input to the Digital-to-Analog Converter (DAC), which in turn sampled the NRZ signals into a single 4-PAM signal. The reason to use a AWG and a DAC to create the electrical 4-PAM signal and not just the AWG alone, is the avoidance of the pre-compensation needed at the AWG in order to create an equally

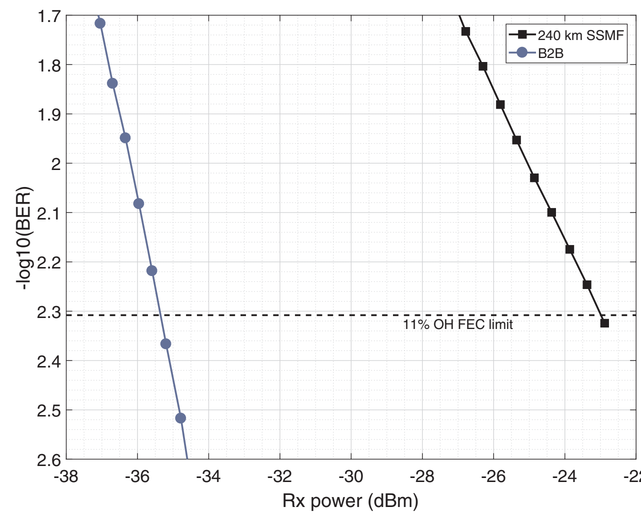

Fig. 4. BER as function of receiver power (Rx power) for back-to-back and 240 km SSMF transmission.

clean electrical signal.The electrical 4-PAM signal was amplified 16 dB, to a peak to peak power of 4 V. A 6 dB attenuation was placed before the EML to minimize electrical reflections and matching the optimum input signal to the modulator of 2 V peak-to-peak. The 40 GHz EML with integrated Continuous Wavelength (CW) source was emitting at 1553.0 nm with an optical output power of 3.75 dBm. The optical output was connected to a Variable Optical Attenuator (VOA) to control the launched power into the transmission link, followed by a 20 dB coupler for signal monitoring (Point A in Fig. 2). The total transmission link consisted of 240 km SSMF. The total length of 240 km was divided into 3 spans each included 80 km SSMF fibers, a Dispersion Compensating Module (DCM) and an Erbium Doped Fiber Amplifier (EDFA). The EDFA resided inside the DCM in Fig. 2, and provided 20 dBm output power with a 6 dB noise figure. Each DCM also included a DCF for the 80 km SSMF. This insured that the total transmission link of 240 km was ~ 100% dispersion and the fiber loss compensated. After the link, a 0.5 nm optical filter was used to remove Amplified Spontaneous Emission (ASE) from the EDFAs in the link. Following the optical filter, another VOA and a 10 dB coupler was used to adjust and measure the received optical power(Point B in Fig. 2). After the VOA a preamplified 40 GHz Photo Diode (PD) was used to convert the optical signal into the electrical domain. Optical preamplification before detection was done, by using another EDFA with constant pump power and <4.3 dB noise figure. After the final EDFA a 0.9 nm adjustable optical filter was used to remove out of band ASE noise before the PD. The electrical signal from the PD was amplified 26 dB with an electrical amplifier before being sampled with a 80 GSa/s Digital Storage Oscilloscope (DSO) with a bandwidth of 33 GHz, where traces were stored for offline processing. The Digital Signal Processing (DSP) consisted of lowpass filtering and resampling of the signal (Point C in Fig. 2), before the signal was equalized by a Decision-Feedback Equalizer (DFE) with 41 forward and 21 feedback taps spaced at half the symbol rate. The DFE was controlled

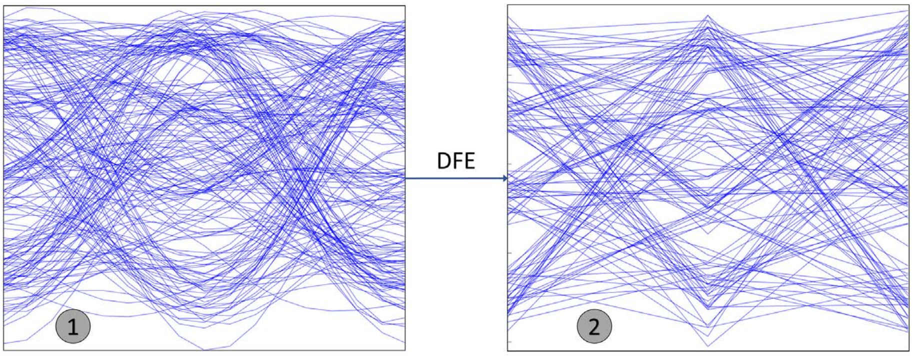

Fig. 5. Offline processing signal clean-up by the use of DFE.

by a Decision-Directed Least-Mean-Square (DD-LMS) algorithm. After the equalizer, the Bit Error Rate (BER) was calculated by bit-by-bit counting.

3. Results

To determine the optimal launch power into the transmission link, a transmitted power measurement versus calculated BER was performed. The transmitter power was measured at point A in Fig. 2 and the VOA at point B Fig. 2 was set to attenuate 0 dB. The result from the measurement is shown in Fig. 3. From the curve with the diamond markers it is observed, that with a transmitter power of −7.5 dBm the BER drops below 2.32 on the $-log_{10}$(BER) scale, which is the 11% OverHead (OH) FEC code [9] and the transmission performance can be considered error free. The lowest BER is reached at a transmitter power of −7 dBm, which is the most optimal transmitter power for this system. −7 dBm is chosen as transmitter power for the BER measurement performed later. At higher powers of transmission, worse BER performance is observed. this indicates that the transmission is limited by nonlinearities caused by high amplification from the first EDFA in the transmission link, located just after point A in Fig. 2.

The results from the BER measurements are shown in Fig. 4. the figure shows the systems BER performance for optical back-to-back (B2B) and the total transmission link of 240 km. The B2B measurement is done by connection point A and B in Fig. 2 with an ordinary optical patch cord. Seen from Fig. 4, in the B2B scenario (curve with dotted markers), a receiver power higher than −35.65 dBm results in a BER below the 11% OH FEC limit. When transmitting over the total transmission link of 240 km (curve with square markers), a BER below the 11% OH FEC limit is reached with a receiver power of −22.9 dBm. This indicated that transmitting over 240 km can be done at a 12.75 dB penalty compared to the B2B transmission.

In Fig. 5 is two eyediagrams. Eyediagram 1 shows the eye after the lowpass filtering in the offline processing (point C in Fig. 2) and eyediagram 2 shows the eye after the implemented DFE. As can be seen the DFE provides the necessary improvement needed to get below the 11% OH FEC limit.

4. Conclusion

An experimental validation of 28 Gbaud 4-PAM over 240 km of SSMF link using simple IM-DD scheme was achieved. With the use of 11% OH FEC and the implementation of DFE with 41 forward and 21 feedback taps, we achieved error free transmission of data rates of 56 Gbit/s. These results show that 4-PAM modulation on inter data center links using IM-DD is a viable solution with no need for re-engineering transmission link design. At the transmitter side, the system uses EMLs with the beneficial prospect of low cost and decreasing the required footprint.

Acknowledgements

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