New Field Trial Distance Record of 3040 km on Wide Reach WDM with 10 and 40 Gbps Transmission Including OC-768 Traffic Without Regeneration

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Abstract: Verizon, Xtera, and Mintera successfully transmitted 40Gbps over 3040Km with RZ-DPSK and 2560Km with CS-RZ on an all-Raman ULH system loaded with 68x10Gbps channels on Verizon's network. Real traffic OC-768 data-streams from Juniper routers were successfully propagated.

OCIS codes: (060.2330) Fiber optics communications; (060.4080) Modulation

Introduction

After two successful field trials at 40Gbps over Verizon's metro ring in San Jose and 1200 km ULH field trial from Sacramento, CA to Salt Lake City, UT in 2004 [1, 2]; Verizon, Xtera and Mintera teamed up for a 10/40Gbps ULH field trial at a record distance of 3040 km on Verizon's Dallas metro SSMF fiber ring in November 2005. This field trial was conducted under the high loss conditions due to the numerous metro ODF connectors. For every 80 kilometer span, the loss on the fiber is about 21 dB, with an average of 5 dB loss for connectors. There was no special inline dispersion compensation used for the RZ-DPSK 40Gbps signal [3]. The ULH system [4] with its 100 nm spectrum window, covering C to extended L band, can provide 240x10Gbps channels at 50 GHz channel spacing, or 120x40Gbps channels at 100 GHz channel spacing. It also provides flexible Raman gains, ranging from 10 dB to 75dB. This field investigation of a 10/40Gbps overlay carrying an OC-768 application demonstrates that optical 40Gbps is a viable solution to be considered for future deployment. In addition to the RZ-DPSK format, CS-RZ at 40Gbps was also tested; an end ~10^{-4} BER was obtained after 2560 km without OEO. This is the first demonstration of CS-RZ at 40Gbps over such a distance in a field environment. The basic 10/40Gbps ULH trial setup environment is shown in Figure 1.

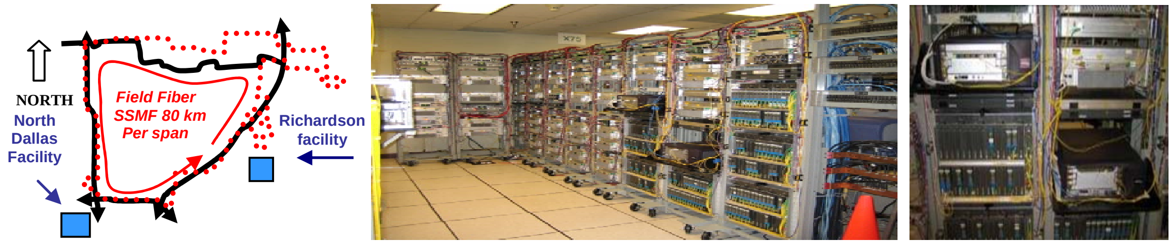

Fig. 1. Verizon 80 km loop, Xtera 3040 km all-Raman ULH system, Mintera 40Gbps transponders.

Trial Configurations and Results

A field trial using Verizon's metro SSMF optical cable running around North Dallas, Texas was conducted using an All-Raman ULH system, 40Gbps transponders and Juniper T640 routing platforms. Two ULH trial distances were configured. The first configuration carried 2×40Gbps channels (CS-RZ and RZ-DPSK) and 68×10Gbps NRZ channels over 2560 Km, the transmission limit for 40Gbps CS-RZ. The second configuration was set at 3040 km; the 40Gbps CS-RZ channel was replaced by a 10Gbps NRZ channel. The 40Gbps RZ-DPSK was error-free after E-FEC and exhibited a 3.5 dBQ margin. The Verizon's cable used in this trial, installed on year 19xx, contains 432

SSMF optical fibers of 80 km in length, with revenue baring traffic on some of the fibers. 32 of these fibers were used to assemble the 2560 km system; then the distance was extended to 3040 km by adding 6 more spans to the link configuration. Each fiber goes through 8 ODFs, adding up to a total of 576 and 684 connectors for the two configurations respectively. The average span loss, as reported by the EMS, was 20.6 dB, including all connector losses.

The architecture of the All-Raman wideband amplifier is schematically shown in fig. 2 left. Three stages of amplification are used: a distributed stage and 2 discrete stages constituted of negative dispersion fiber, which also helps to partially compensate the span positive dispersion. One of the biggest challenges in the design of a wide band amplifier is to keep the noise figure low across the entire signal spectrum. The optimized choice of pump wavelengths and pump levels for these amplifiers results in an equivalent noise figure less than 1 dB [4].

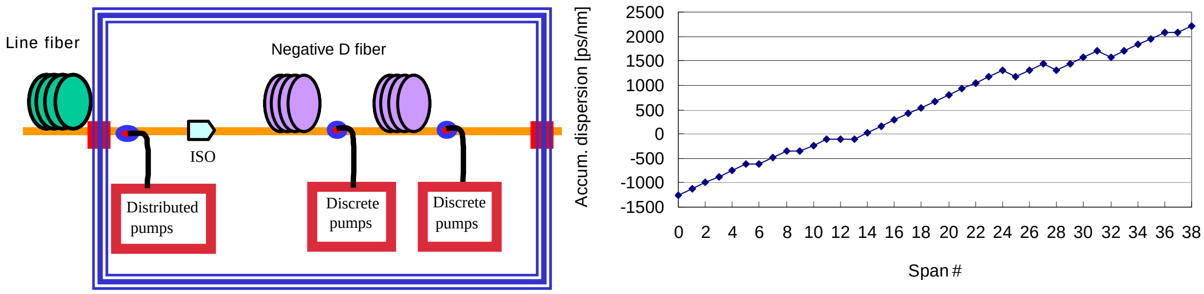

Fig. 2. Left: All-Raman amplifier structure. Right: 3040 Km link accumulated dispersion for a 10Gbps channel.

The 100 nm amplifier bandwidth is divided in four sub-bands of 60 channels each. The link's residual dispersion is compensated at the terminal's sub-band amplifiers with the proper amount of DCF that makes each sub-band channel error-free with an adequate margin. Channel aggregation of 50 GHz-spaced 10Gbps channels is obtained by two 30 channels x 100 GHz Mux/Demux per sub-band. At the drop side, an interleaver, besides demultiplexing odd and even channels, is used to limit the signal bandwidth reaching the receivers. Due to the larger spectrum of the 40Gbps channels transmitted in sub-band 3, the interleaver was removed in this band only. Fig. 2 right shows the accumulated dispersion at 1550.75 nm for the 3040 Km link. Residual dispersion of the 40Gbps transponders needed a finer tuning compared to the 10Gbps transponders.

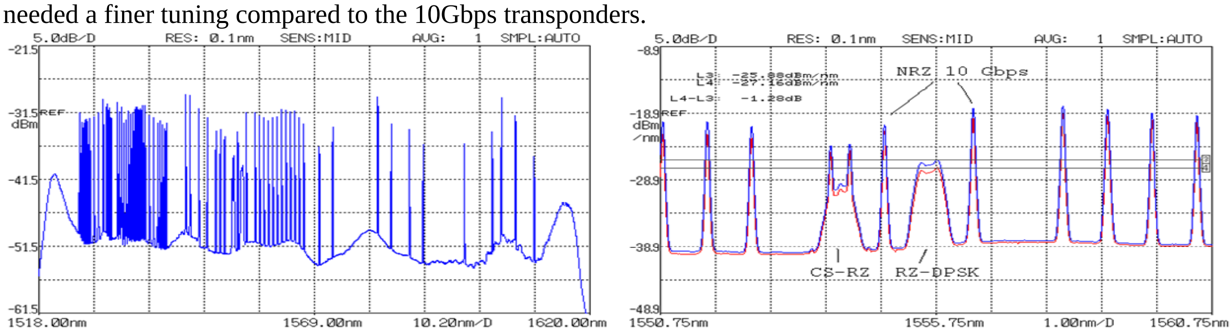

Fig. 3. Optical spectra at 2560 Km. Right picture shows the signal fluctuation due to PDL-PDG after 10 days.

The standard tolerance window (±50 ps/nm) of the 40 Gbs channels is extended to 500 ps/nm with the help of a tunable grating dispersion compensator incorporated into the transponders, which also introduces an offset in dispersion of about 400 ps/nm. In order to center the residual dispersion in this window, an extra CD compensation was added at the launch side to each transponder; for the 2040 Km link the additional CDC amounted to -400 ps/nm and to -900 ps/nm for the 3040 Km link.

The two 40Gbps transponders were at 1554.14 nm (CS-RZ) and 1555.75 nm (RZ-DPSK). 68x10Gbps transponders were also present; the resulting spectrum at the output of the 2560 Km link is shown in Figure 3 left. The launched power and distributed Raman gain have been optimized for this particular configuration to minimize the ripple: the 10Gbps channels power was set at -3.5 dBm; the measured ripple at the output of the 32^{nd} (2560 km) amplifier was less than 8 dB. The 40Gbps channels powers were optimized individually to minimize the BER and both resulted in -2 dBm. The amount of signal fluctuation at the receiver side (fig. 3 right), due to PDL-PDG of the link, is 1.3 dB after 10 days; the corresponding OSNR fluctuation is less than 1 dB. In figure 4 left, a plot of BER vs. time is shown for the 40Gbps channels and the two 10Gbps channels interleaved with them (refer to fig. 3 right).

On the right, the Q values calculated from pre-FEC BER are plotted. Average Q of all 10Gbps channels is 14.7 dB; the corresponding average OSNR is 17.2 dB. The lowest Q was recorded for the channel at the beginning of band 1

(1609.63 nm) where the dispersion was not compensated accurately and the ripple was high. Measured Q is 13.8 dB and OSNR is 18.7 dB for the RZ-DPSK channel; Q is 10.8 dB and OSNR is 17.2 dB for the CS-RZ channel. The 10Gbps NRZ channels use a standard Reed-Solomon FEC [RS(255,239)] and thus need a minimum input Q of 11.5 dB for error-free (10^{-15} BER) operation; the E-FEC adopted in the 40Gbps channels needs a minimum Q of 9.5 dB for the same output BER.

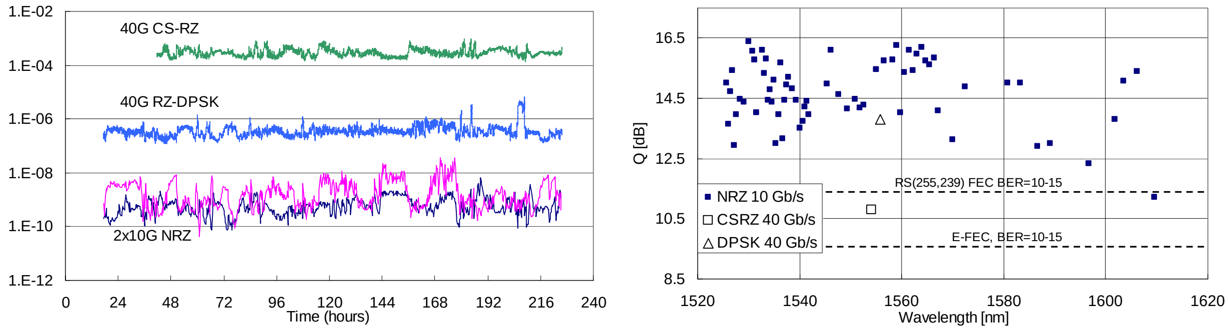

Fig. 4. 2560 Km link: BER traces on left refer, from top to bottom, to CS-RZ, RZ-DPSK and the 2 10Gbps channels near the 40Gbps ones. Q values for all channels are shown on the right, together with the FEC limits for 10^{-15} BER.

The 3040 Km link was obtained by simply adding 3 more spans at both ends of the 2560 km link, leaving the terminal configuration unchanged. The same amounts of DCF at the receiver were used, even if the residual dispersion of the link was about 700 ps/nm larger. The CS-RZ channel was substituted by a 10Gbps channel at the same wavelength, so that a total of 69 10Gbps transponders were present. Figure 5 left shows the measured Q values for this link: the average Q of the 10Gbps channels is 13.8 dB, with a minimum of 11.5 dB at 1570.1 nm and a maximum of 16.0 dB at 1530.73 nm; the average OSNR is 16.9 dB. The RZ-DPSK channel has a Q of 13.2 dB with an OSNR of 17.9 dB. In a back-to-back measurement performed on this unit at the same OSNR, a Q of 14.3 dB was measured, only 1.1 dB above the value measured on the 3040 km link, indicating that the non-linear penalty was quite low. The optical spectrum ripple at the output of the 38th (3040 km) amplifier was about 7 dB, less than the 2560 km link, thanks to adjustments in amps settings.

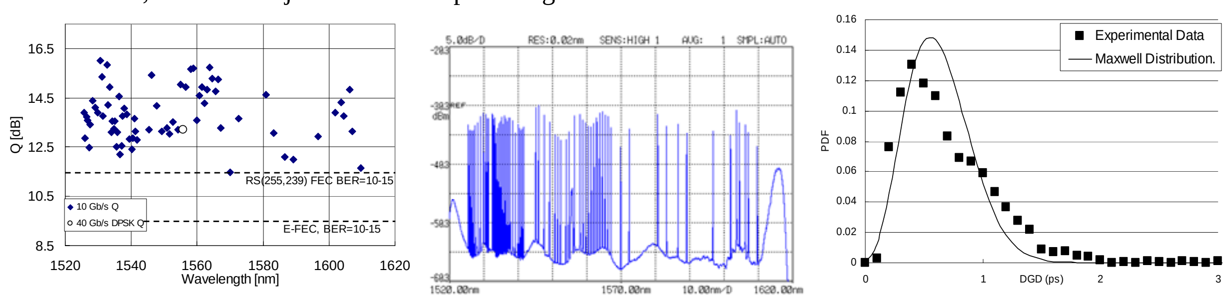

Fig. 5. 3040 Km link: From left to right: Q values, output spectrum and DGD PDF for the line.

Estimate of the fiber PMD coefficient was performed with an Agilent 8509 PMD Analyzer using 2 different methods, Stokes Parameters Analysis (SPA) and Jones Matrix Eigenvalues (JME) [5], on a sample of 20 out of the 38 spans, and over the wavelength range 1510-1600 nm. Figure 5 right shows the resulting DGD PDF from the JME measurements. Both methods give an average PMD coefficient for the fiber of 0.07 ps/sqrt (km), which corresponds to a total average DGD of 4.3 ps, amplifiers included.

Conclusion and future work

68 10Gbps NRZ channels and 2 40Gbps (CS-RZ and RZ-DPSK) channels were successfully transmitted using an All-Raman based wide reach DWDM platform in a field environment. No architecture changes were required for the ULH system to support the 40Gbps channels. PMD has been measured to be low enough to ensure error-free transmission over the entire test period of three weeks. To our knowledge, it is the first field demonstration of a ULH system containing 10/40Gbps channels over several thousand km.

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