Technical Paper

New field trial distance record of 3040 km on wide reach WDM with 10 and 40 Gbps transmission including OC-768 traffic without regeneration

David Z. Chen, Tiejun J. Xia, Glenn Wellbrock, Verizon Communications Inc.,

Pavel Mamyshev, James J. Zik, Steve Penticost, Mintera Optical Networks,

Guido Grosso, Allen Dismukes, Philippe Perrier, Hervé Fevrier,
Xtera Communications

Abstract

Verizon successfully carried Juniper OC-768 traffic on their Richardson, Texas, field trial network to 3040km and 2560km, respectively, using Mintera's 40Gbps RZ-DPSK and CS-RZ transponders over Xtera's all Raman ULH system loaded with 68x10Gbps channels.

1. Introduction

After two successful field trials at 40 Gbps over Verizon's metro ring in San Jose, Calif., and a 1200 km ULH field trial from Sacramento, Calif., to Salt Lake City, Utah, in 2004 [1, 2]; Verizon, Xtera, and Mintera teamed up for a 10/40 Gbps 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 high loss conditions because of the numerous metro ODF connectors. For every 80 kilometer span, the fiber loss is about 21 dB, including an average of 5 dB loss for connectors. No special inline dispersion compensation was used for the RZ-DPSK 40 Gbps signal [3]. The ULH system [4] with its 100 nm spectrum window, covering C to extended L band, can provide 240x10 Gbps channels at 50 GHz channel spacing, or 120x40 Gbps channels at 100 GHz channel spacing. The system also provides flexible Raman gain, ranging from 10 dB to 75 dB. This field investigation of a 10/40 Gbps overlay carrying an OC-768 application demonstrates that 40 Gbps is a viable solution to be considered for future deployment. In addition to the RZ-DPSK format, CS-RZ at 40 Gbps also was tested out to 2560 km without OEO regen. This is the first demonstration of CS-RZ at 40 Gbps over this distance in a field environment. The basic 10/40 Gbps ULH trial setup environment is shown in Fig. 1.

Figure 1: Left to right: Verizon 80km loop; Xtera 3040km all-Raman ULH system; Mintera 40 Gbps transponders

Source: Optical Fiber Communications Conference 2006
Key topics: Wide reach all-Raman DWDM system, 40G transmission
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2. Trial configurations and results

A field trial using Verizon's metro SSMF optical cable running in the north Dallas area was conducted using an all-Raman ULH system, 40 Gbps transponders, and Juniper T640 routing platforms. Two ULH trial distances were configured. The first configuration carried 2×40 Gbps channels (CS-RZ and RZ-DPSK) and 68×10 Gbps NRZ channels over 2560 km, the transmission limit for 40 Gbps CS-RZ. The second configuration was set at 3040 km; the 40 Gbps CS-RZ channel was replaced by a 10 Gbps NRZ channel. The 40 Gbps RZ-DPSK was error-free after E-FEC and exhibited 3.5 dBQ of margin. Verizon's Richardson, Texas, test network used in this trial was installed in the late 1990s and contains 80 km of 432 SSMF optical fibers, a portion of which carry revenue-bearing traffic. Thirty-two of these fibers were used to assemble the 2560 km system. The distance was extended to 3040 km by adding six more spans to the link configuration. Each fiber goes through eight ODFs, adding up to a total of 576 and 684 connectors, respectively, for the two configurations. 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 two discrete stages consisting of negative dispersion fiber, which helps to partially compensate the span positive dispersion. One of the biggest challenges in the design of a wide band amplifier is to maintain a low noise figure 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].

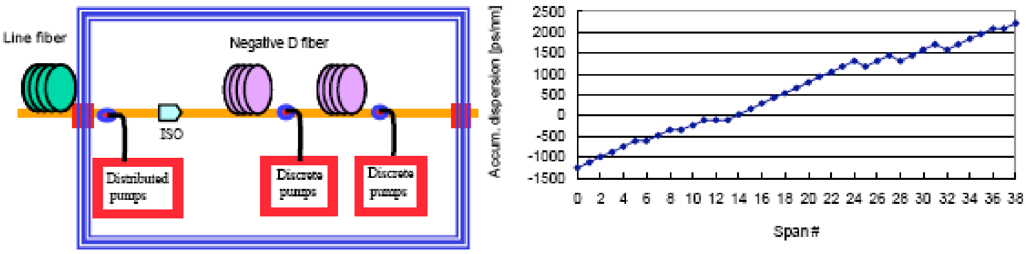

Figure 2: Left: All-Raman amplifier structure. Right: 3040km link accumulated dispersion for a 10 Gbps channel.

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, making each sub-band channel error-free with adequate margin. Channel aggregation of 50 GHz-spaced 10 Gbps channels is obtained by two-30 channels x 100 GHz Mux/Demux per sub-band. At the client side, an interleaver demultiplexing odd and even channels, limits the signal bandwidth reaching the receivers. Due to the larger spectrum of the 40 Gbps 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 40 Gbps transponders needed finer tuning than the 10 Gbps transponders.

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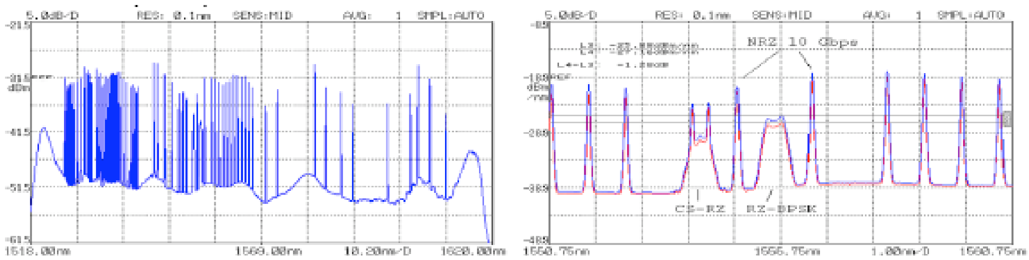

Figure 3: Left: Optical spectra at 2560km. Right: Signal fluctuation due to PDL-PDG after 10 days.

The standard tolerance window (±50 ps/nm) of the 40 Gbps channels is extended to 500 ps/nm with the help of a tunable grating dispersion compensator incorporated into the transponders. The compensator also introduces an offset in dispersion of about 400 ps/nm. In order to center the residual dispersion in this window, extra CD compensation was added at the launch side to each transponder. The additional CDC amounted to -400 ps/nm for the 2560 km link and -900 ps/nm for the 3040 km link.

The two 40 Gbps transponders were at 1554.14 nm (CS-RZ) and 1555.75 nm (RZ-DPSK). The 68x10 Gbps transponders also were present as shown in the resulting spectrum in Fig. 3, Left. The launched power and distributed Raman gain have been optimized for this particular configuration to minimize the ripple. The 10 Gbps channel power was set at -3.5 dBm and the measured ripple at the output of the 32nd (2560 km) amplifier was less than 8 dB. The 40 Gbps channel 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 with a corresponding OSNR fluctuation of less than 1 dB. In Fig. 4, Left, a plot of BER vs. time is shown for the 40 Gbps channels and the two 10 Gbps channels interleaved (Fig. 3, Right).

On the right, the Q values calculated from pre-FEC BER are plotted. Average Q of all 10 Gbps channels is 14.7 dB, with a corresponding average OSNR of 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 and measured Q is 10.8 dB and OSNR is 17.2 dB for the CS-RZ channel. The 10 Gbps 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 40 Gbps channels needs a minimum Q of 9.5 dB for the same output BER.

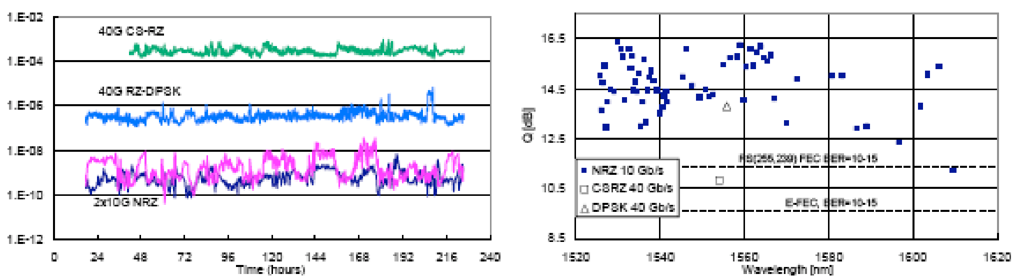

Fig. 4. 2560 km link: Left: BER traces, from top to bottom, CS-RZ, RZ-DPSK, and the two 10 Gbps channels near the 40 Gbps channels. Right: Q values for all channels with the FEC limits for 10^{-15} BER.

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The 3040 km link was obtained by simply adding three additional spans at both ends of the 2560 km link, leaving the terminal configuration unchanged. The same amount of DCF was used at the receiver, despite the residual dispersion of the link measuring about 700 ps/nm larger. The 40 Gbps CS-RZ channel was substituted with a 10 Gbps channel at the same wavelength, for a total of 69 10 Gbps transponders. Fig. 5, Left, shows the measured Q values for this link. The average Q of the 10 Gbps 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 with an average OSNR of 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 obtained, only 1.1 dB above the value measured on the 3040 km link, indicating 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 amplifier settings.

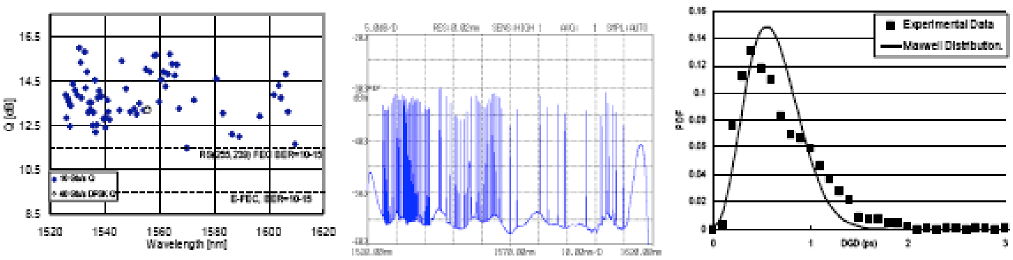

Fig. 5. 3040 km link: Left to right: Q values, output spectrum, and DGD PDF for the line.

Estimate of the fiber PMD coefficient was performed with an Agilent 8509 PMD Analyzer using two different methods, Stokes Parameters Analysis (SPA) and Jones Matrix Eigenvalues (JME) [5], on a sample of 20 of the 38 spans and over the wavelength range 1510-1600 nm. Fig. 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, including amplifiers.

3. Conclusion and future work

Sixty-eight 10 Gbps NRZ channels and two 40 Gbps (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 40 Gbps channels. PMD was measured at rates low enough to ensure error-free transmission over the entire test period of three weeks. To our knowledge, this trial is the first field demonstration of a ULH system containing 10/40 Gbps channels over several thousand kilometers.

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David Z. Chen, Tiejun J. Xia, Glenn Wellbrock
Verizon Communications Inc.,
2400 N. Glenville Drive, Richardson, Texas 75082
T (972) 729-5624
F (972) 729-5392,
E david.chen@verizon.com

Pavel Mamyshev, James J. Zik, Steve Penticost
Mintera Optical Networks,
35 Nagog Park, Acton, MA 01720
T (978) 929-2811,
F (978) 645-1381,
E pavel.mamyshev@mintera.com

Guido Grosso, Allen Dismukes, Philippe Perrier, Hervé Fevrier
E ggrosso@xtera.com

Contact: **Corporate Headquarters**
Xtera Communications - USA
500 W. Bethany Drive, Suite 100
Allen, TX 75013
USA

T + 1 972 649 5000
F + 1 972 747 0344

E info@xtera.com
www.xtera.com

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