Field trial of a 40 Gbit/s PSBT channel upgrade to an installed 1700 km 10 Gbit/s system

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Abstract: This paper presents the results of three practical experiments proving the viability of 40 Gbit/s Phase-Shaped Binary Transmission (PSBT) channel upgrade to existing 10G systems supporting 50 GHz channel spacing: (a) Lab experiments with a fully loaded 1000 km 80-channel 10 Gbit/s system upgraded with two 40 Gbit/s PSBT channels. (b) An 850 km field trial of 40 Gbit/s PSBT channel upgrade to an installed 10 Gbit/s system and installed fiber. (c) An extension of the 850 km field trial to 1700 km via optical loop back. The 10 Gbit/s system was left as originally provisioned and all link control loops were active during the trials. Error free performance after FEC was achieved for all three experimental configurations, proving flexible and seamless 40 Gbit/s PSBT channel upgrade to existing 10 Gbit/s systems is possible and practical.

OCIS codes: (060.2330) Fiber optics communications; (060.4250) Networks

1. Introduction

As Internet traffic continues to grow, scaling the Internet backbone will continue to be a challenge. Although earlier claims of bandwidth doubling every 100 days were over-optimistic, Internet growth is still predicted to grow by 1.7x to 2.5x per year over the next decade [1]. With the commercial availability of next generation IP routers employing 40 Gbit/s interfaces to support this growth comes the requirement to interconnect these routers across the WAN.

Due to the different capacities, service interfaces, and inherent reach of 10 Gbit/s and 40 Gbit/s DWDM systems, the most cost-effective transport solution will employ both in the network. For capacity demands with high growth rates and moderate reach (<1500km), 40 Gbit/s can be deployed without the need for intermediate regeneration. For ULH demands, connectivity is best supported with 10 Gbit/s channels, leveraging their inherent reach advantage to minimize OEO regeneration costs.

This paper describes 10 and 40 Gbit/s multi-haul DWDM testing in both laboratory and field environments, proving the viability and practicality of multi-haul transmission. Field trial testing over an installed 850 km 10 Gbit/s system deployed between Seattle, WA to Bandon, OR showed error free transmission with a Q margin exceeding 4dB. Error free transmission of the 40 Gbit/s channels was also achieved over a 1700 km loopback configuration in the field trial, which included 3 intermediate OADMs supporting 50GHz channel spacing add/drop. The DWDM system used in the trials supports any mixture of 10 Gbit/s and 40 Gbit/s wavelengths on a 50GHz ITU grid. The use of a spectrally efficient Phase-Shaped Binary Transmission (PSBT) modulation format for the 40 Gbit/s channels offers a number of advantages over the use of NRZ or CS-RZ [2,3,4,5], such as:

1. Operation on a 50GHz channel spacing (0.8bit/s.Hz spectral efficiency), including R-OADM
2. Wide chromatic dispersion tolerance of 300ps/nm
3. Any mix of 10 Gbit/s and 40 Gbit/s wavelengths, no requirement for wavelength sub-bands
4. Launch power compatible with existing 10 Gbit/s design rules

2. Laboratory experiment

To prove the seamless upgradeability of this 10 Gbit/s system to 40 Gbit/s channels, tests were first performed in the lab with a pre-production version of the 40 Gbit/s transponders over the existing 10 Gbit/s system. A 1,000 km system with 3 optical add/drop multiplexers (OADM) along the transmission path was used for the lab tests. The transmission link consisted of 12 spans of 80 km Standard Single Mode fiber (SSMF), 1997 vintage, with each span attenuated to 21 dB. The transmission system was optimized for 10 Gbit/s channels, with 80 10 Gbit/s channels in the C-band at 50 GHz spacing. For the multi-haul experiments, 78 channels were populated with 78 10 Gbit/s NRZ transponders employing 25% overhead FEC. Two channels were populated with 40 Gbit/s PSBT transponders employing 7% overhead E-FEC. The 40 Gbit/s channels were added at the standard multiplexer ports and interleaved to 50GHz channel spacing (approximately 40GHz filter bandwidth). Launch power was comparable, at about +1 dBm, for the 10 Gbit/s and 40 Gbit/s channels. The amplifiers were three stage erbium doped fiber amplifiers (EDFA) with mid-stage access for chromatic dispersion compensation. The system was running with full optical link control to balance optical gain tilt and spectral shape. The OADMs were based on a broadcast-and-select wavelength blocking architecture with a spectral width of around 35 GHz per channel.

The system was optimized for 10 Gbit/s NRZ transmission, so the post-compensation was varied to determine the 40 Gbit/s chromatic dispersion tolerance and optimize performance. Aside from the adjustment of the post compensation, the system was left untouched. The 40 Gbit/s channels exhibited more than 2 dB Q margin over the link with an optical signal to noise ratio (OSNR) of 19.8 dB. Both channels were error free after FEC for 48+ hours, as measured via an OC-768 SONET test set connected to the client interface. The SONET test set was configured for OC-768c transmission with a 2^{31}-1 PRBS pattern in the payload.

Disabling the two 50 GHz-spaced 10 Gbit/s channels adjacent to the 40 Gbit/s channels improved the Q margin by approximately 0.5 dB. Disabling the next adjacent channel on either side had no further impact on the 40 Gbit/s performance. The impact of adding a 40 Gbit/s channel to the existing 10 Gbit/s channels was found to be minimal, comparable to that of adding a 10 Gbit/s channel at the same frequency and channel spacing.

3. Field experiments at 850 km

Next, a 10/40 Gbit/s multi-haul field trial was conducted over the AT&T network connecting Bandon, Oregon and Seattle, Washington. The transmission distance for the link was 850 km, and the link consisted of 12 fiber spans in each direction. Two of the fiber spans were TrueWave-Classic fiber, 10 were SSMF. Span lengths ranged from 50km to 88km. Insertion losses ranged from 15 to 22 dB, with an average loss of 17 dB. The polarization mode dispersion (PMD) of the route was below 0.1 ps/sqrt(km). On this route, a R-OADM was present in Portland, OR. A total of seven transponders were equipped in each direction, one 40 Gbit/s PSBT transponder at 193.5 THz, two 10 Gbit/s transponders on either side (193.40, 193.45, 193.55 and 193.60 THz) for a total cluster of 5 wavelengths at 50 GHz spacing. The other two wavelengths on the system were towards the end of the C-band, used for other testing.

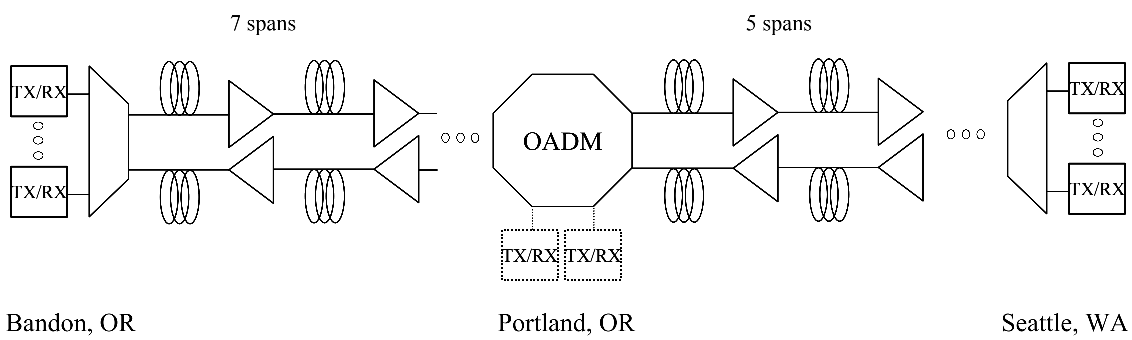

Fig. 1: Diagram of the field-installed system over installed fiber between Bandon and Seattle.

The transmission system was the same type as used for the lab experiments. All link optimizing control loops were running and no adjustment was made to accommodate the 40 Gbit/s channels, apart from adjusting the pre- and post compensation, which did not influence the existing system. To monitor the post-FEC BER, an OC-768 SONET test set was connected to the 40 Gbit/s transponder in Seattle with the client interface on the 40G transponder in Bandon in optical loop-back on itself with an optical fiber jumper. The SONET test set was configured for OC-768c transmission with a 2^{31}-1 PRBS pattern in the payload.

A newer generation of the fully C-band tunable 40 Gbit/s PSBT transponder was used for the field trial, with enhanced performance (optimized transmit/receive drive chain electronics) relative to the generation used in the lab trial. Pre/post compensation for the 40G channels was varied by inserting DCMs between the 40 Gbit/s transmitter/receiver and the mux/dmux, respectively. A chromatic dispersion tolerance greater than 150 ps/nm was measured for a 0.5dB Q penalty on this route (see Fig. 2). This large CD tolerance eliminates the need for tunable dispersion compensation and makes 40 Gbit/s deployments practical.

For initial experiments, the 10 Gbit/s channels at 193.45 THz and 193.55 THz were disabled. Approximately 3.5 dB and 4.5 dB Q margin was measured for the southern and northern routes, respectively, at 100 GHz channel spacing. In comparison to lab trial results over similar links, it is estimated that the ONSR margin on the southern route exceeded 6 dB for this 100 GHz experiment. The post FEC BER was verified to be error free. The two 10 Gbit/s channels were then activated at 193.45 THz and 193.55 THz, providing the cluster of 5 channels at 50 GHz channel spacing centered on the 40 Gbit/s channels. The margin of the 40 Gbit/s channels was reduced by approximately 1 dB due to the presence of these 50 GHz-spaced 10 Gbit/s channels, but significant margin was still present over the link. In previous lab experiments over this system, the impact of the 40 Gbit/s channels on the 10 Gbit/s channels has been found to be negligible so the impact was not measured during the trial. Performance of the 40 Gbit/s channels could have been improved by optimizing the 40G channel launch power, but this was not within the scope of the trial.

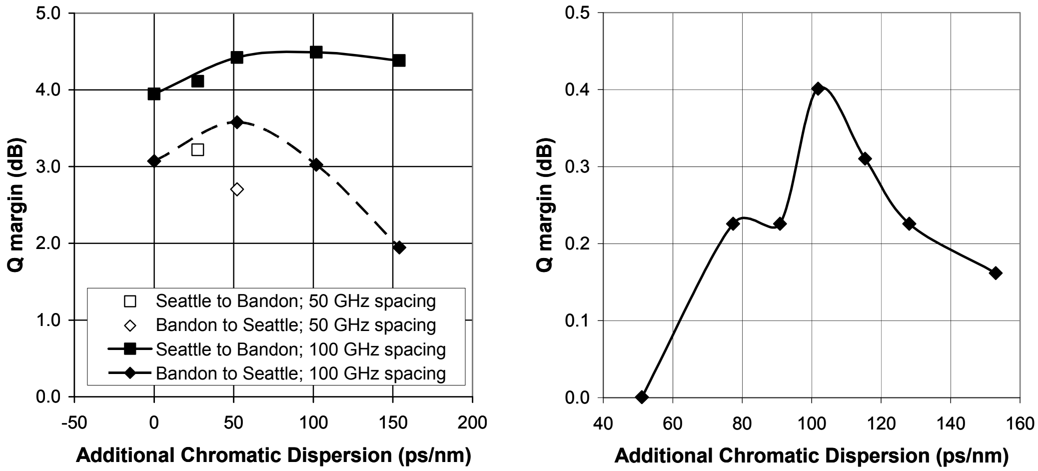

Fig. 2: Q margin as a function of link chromatic dispersion for the 850 km field trial link (left graph) and 1700 km loopback field trial link (right graph). Q margin is measured relative to the FEC correction limit. Chromatic dispersion values are given relative to the residual link dispersion.

4. Field experiments at 1700 km

To further evaluate the performance of the 40 Gbit/s PSBT channels over the system, the 40 Gbit/s channel was optically looped back at the Bandon site to provide a total transmission distance of 1700km. An optical amplifier was added between the mux/dmux to overcome the loss associated with the DCM and loop-back. For these experiments, the 10 Gbit/s channels at 193.45 THz and 193.55 THz were disabled. The pre- and post dispersion compensation stayed the same as in the 850 km experiment, with a DCM inserted at the loop-back prior to the amplifier. As before, all control loops were enabled. In this configuration, the 40 Gbit/s channel traveled 1700 km and passed through three 50 GHz OADMs (2 broadcast-and-select OADMs and one full mux/dmux OADM) without regeneration. The margin over the link was 0.4 dB and the post-FEC BER was error free for this 100 GHz experiment, measured by the OC-768 test set (see Fig. 2). Enabling the 50 GHz spaced channels again, we could decode the FEC error free, but got bit error hits on small adjustments of the optical link power balance control, showing that there was no excess margin leftover.

5. Summary and conclusions

Lab and field trials have been performed, proving the viability and practicality of spectrally efficient 10/40 Gbit/s multi-haul DWDM transmission. Seamless 40 Gbit/s upgrade to the existing 10 Gbit/s transmission system was demonstrated in lab and field trial environments using spectrally efficient and impairment robust 40 Gbit/s PSBT transponders. These 40 Gbit/s PSBT transponders supported OC-768c framing, which was used for all testing reported here. The first field trial, consisting of an 850 km link with one intermediate OADM showed up to 4.5 dB of Q margin and a large chromatic dispersion tolerance. The second field trial was over a 1700 km link with 3 OADMs. Margin above the FEC threshold was achieved and error free performance after FEC was confirmed via an OC-768 SONET test set connected to the client interface.

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