Multi-Rate (111-Gb/s, 2x43-Gb/s, and 8x10.7-Gb/s) Transmission at 50-GHz Channel Spacing over 1040-km Field-Deployed Fiber


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Abstract

111-Gb/s transmission combined with 2x43-Gb/s and 8x10.7-Gb/s on a 50-GHz grid over 1,040-km field fiber and two ROADM is demonstrated, showing the feasibility of 100G overlaying existing 10G/40G commercial systems.

Introduction

Due to many new bandwidth-intensive applications, such as video and interactive TV, overall bandwidth demand is expected to see another explosion in growth over the next few years. Therefore, next generation optical transmission with data rates around 100 Gb/s (100G technology) has attracted a lot of attention. In recent years both transport equipment developers and telecom carriers have spent significant effort on 100G research and development [1-7]. Most reported results, however, are tests in laboratory environment, while a few serial 100G field trials have been reported [8-10].

The advent of the 100G technology to address the capacity increase will have to cope with the existing WDM infrastructure carrying 10G and 40G wavelengths today. It is desired to upgrade networks mixing 10G, 40G and 100G channels, with any channel plan without traffic interruption [11]. Thus, we have conducted a field trial to demonstrate the feasibility of accommodating 10G, 40G and 100G with standard 50-GHz channel spacing. In this paper, we characterize the optical transmission performance of a 111-Gb/s coherently demodulated polarization multiplexed (CP) RZ-QPSK channel with electronic post-processing, neighboring both 10.7-Gb/s OOK and 43-Gb/s DPSK channels over 1,040-km field deployed fiber in presence of two 50-GHz ROADM.

Field Trial Set-Up

The WDM system used for this trial is composed of Nokia Siemens Networks’ hiT 7500 ultra-long haul (ULH) equipment, which is installed in Verizon’s Network and Technology Lab in Richardson, Texas, USA. The WDM link has thirteen 80-km spans. The 1,040-km link has one ROADM at each end and one center-span ROADM. The 10G, 40G, and 100G channels (10.7 Gb/s, 43 Gb/s, and 111 Gb/s) are fed into the ROADM at the ends of the link. For each span, the composed optical signals are sent to a field fiber in the Dallas metropolitan area. After the signals propagate for 80 km, they are fed into an amplifier with mid-stage dispersion compensation, and then propagate to the next span. The center-
amplifiers consist of EDFAs and no Raman amplification is used. Figure 1 shows the set-up for the trial. The 10G (OOK) and 40G (DPSK) cards are part of the standard commercially available Nokia Siemens Networks product hiT 7500 system. The 100G equipment consists of a full C-band tunable RZ pulse shaped CP-QPSK transmitter with automatic bias control and a coherent receiver. The transmitter is fed by two 27.75-Gb/s PRBS signals with lengths of $2^{23}-1$ bits (data and a delayed inverted data). Inside the transmitter the signals are split, delayed (for de-correlation) and fed into two IQ-modulators. The receiver consists of an integrated tunable laser assembly (ITLA), a QPSK mixer and four 33-GHz photodiodes with integrated TIA. The data is captured by a 50-GS/s digital storage oscilloscope (Tektronix DSA 72004) and processed on a computer. Figure 2 shows a photograph of the 100G set-up.

**Trial Results**

In this trial, the 111-Gb/s channel is placed at 1550.12 nm and the 43-Gb/s and 10.7-Gb/s channels surround the 111-Gb/s channel evenly with 50-GHz channel spacing (Fig. 3). To examine the impact of the neighboring channels on the 111-Gb/s channel, we have analyzed the influence of input power of the 10.7-Gb/s and 43-Gb/s channels to the bit error rate of the 111-Gb/s channel. Figure 4a shows the optimal input power level of the 111-Gb/s channel versus the power levels of 10.7-Gb/s and 43-Gb/s channels. The results show that the launch power of the adjacent channels has to be carefully chosen. With a launch power of +3 dBM for the 10.7-Gb/s and 43-Gb/s channels, the FEC threshold of BER = 2x10^-3 could barely be reached. With launch powers of 0 dBM and below, the 111-Gb/s channel shows BER of better than 10^-4, which is more than sufficient for error-free transmission after FEC.

From the results, it is evident that the optimal input power of the 111-Gb/s channel depends only slightly on the neighboring channels’ power and is in the range of +1 to +3 dBM. By choosing +2 dBM as the input power, the 111-Gb/s channel will operate close to the optimum, almost independently of the power levels of the neighboring channels. We also
examined the BER of the 111-Gb/s channel as a function of the received OSNR, which is depicted in Fig. 4b. It shows that the OSNR margin from FEC threshold exceeds 6 dB if the adjacent 10.7-Gb/s and 43-Gb/s channels are transmitted at 0 dBm or lower. Only a negligible influence from the 111-Gb/s channel on the BERs of its 10.7-Gb/s and 43-Gb/s neighbors was observed at launch power levels of the 111-Gb/s channel reaching 3 dBm. Figure 5 shows the recovered constellation diagrams for the 111-Gb/s CP-QPSK channel for both polarizations, which clearly exhibit very small phase distortion.

A second channel configuration containing only 10.7-Gb/s and 111-Gb/s channels is also tested in this trial. In this configuration the 111-Gb/s channel is neighbored with the OOK-modulated 10.7-Gb/s channels immediately, and therefore the nonlinear phase effects on the 111-Gb/s channel from its neighboring channels are expected to be more severe than the previous case. In this set-up, the 111-Gb/s CP-QPSK channel is surrounded by ten 10.7-Gb/s channels in a 50-GHz grid. The spectrum of this setup is shown in Fig. 6.

In order to investigate the impact from the 10.7-Gb/s OOK channels on the 111-Gb/s signal, the launch channel power levels are varied independently. In Fig. 7, the BER of the 111-Gb/s channel is plotted as a function of its launch power for different input power levels of the 10.7-Gb/s channels. Unlike the previous case where the 111-Gb/s channel was directly surrounded by DPSK-modulated 43-Gb/s, here the 111-Gb/s channel is surrounded by OOK-modulated 10.7-Gb/s channels. To reach the same performance of the 111-Gb/s channel as in the previous case, the launch power of the 10.7-Gb/s channels must be limited to +1 dBm, which is 2 dB lower than the power level of the 43-Gb/s channels. The result shows that the impact of 10.7-Gb/s channels on the 111-Gb/s channel is higher than that of 43-Gb/s channels due to stronger XPM effects from OOK-modulated 10.7Gb/s channels.

One of the major advantages of coherent detection is that it gives an access to both the amplitude and the phase of the optical signals, which enables electronic PMD compensation by using a suitable DSP algorithm [12-13]. In this trial, we have verified this merit with PMD emulators placed in the transmission link. A variable DGD generator and a fiber-based multi-order PMD emulator were used to generate a lumped PMD value in the experiment. The lumped PMD was placed either in the front-end or in the tail-end of the transmission line. The PMD emulator has a mean DGD of 11.2 ps. The DGD generator can provide DGD values up to more than 100 ps. The transmission fiber has a mean DGD of nearly 2 ps. In the trial, the total mean DGD value is estimated based on the lumped PMD value and the value of the transmission line. The input polarization to the PMD and PMD emulators is varied by a polarization scrambler.
10-ps mean DGD) to the system. The mean DGD value of the whole system is calculated based on a quadratic summation of the individual contributions of the segments. For this configuration, in which the lumped PMD is placed in front of the transmission line, the 111-Gb/s channel sustains up to 23-ps mean DGD (60-ps generated DGD, 11.2-ps emulated mean DGD, and 2-ps mean DGD contributed by the 1,040-km transmission fiber), if we set a pre-FEC BER threshold of 2x10^{-3} for error-free operation. The results are shown in Fig. 8a, where the inset box indicates the DGD values generated by the DGD generator and the mean DGD value of the fiber based PMD emulator.

Adding lumped emulated PMD in front of the transmission line may represent the worst-case scenario. That is a finding in this trial. With this configuration, the 111-Gb/s channel experiences a severe distortion before it propagates through the transmission fiber. A portion of the distorted signal may exhibit intensity spikes in the time domain, which can induce higher nonlinear effects than a non-distorted signal. When lumped emulated PMD is placed in the tail-end of the transmission line, however, the PMD effect is purely linear, i.e., no nonlinear effect of the transmission fiber is coupled with the PMD effect. Therefore, this may represent the best-case scenario for the impact of PMD. The trial results have proved this fact. With the lumped emulated PMD placed in the end of the transmission line, the PMD tolerance of the 111-Gb/s channel is much higher than when the lumped PMD is placed at the beginning of the transmission line. Figure 8b shows these results, showing a BER value that is almost independent of the DGD values up to 100 ps. Please note the total PMD value in this scenario includes that of the PMD emulator and that of the transmission fiber, in addition to the DGD values indicated in the inset of Fig. 8b. For this best-case scenario a mean DGD tolerance up to 35 ps is recorded based on the measurements. It is expected the performance of the 111-Gb/s channel in a real field installed fiber system will be between that for the worst-case and the best-case scenarios of this trial.

**Summary and Conclusions**

We have demonstrated the transmission of multiple 10G, 40G and 100G channels (10.7 Gb/s OOK, 43 Gb/s DPSK, and 111 Gb/s CP-QPSK) with a channel spacing of 50GHz, over 1,040-km field deployed fiber using Nokia Siemens Networks’ DWDM platform hiT 7500, with two 50-GHz ROADMs in the optical path. No Raman amplification was utilized. The interplay between the channels with different data rates has been analyzed. We show that the performance of a 111-Gb/s channel is optimized by carefully choosing the power levels of its neighboring 10.7-Gb/s and 43-Gb/s channels. We have performed PMD tolerance tests on the 111-Gb/s channel by adding lumped multi-order PMD in the beginning and the end of the transmission line. The results show that the 111-Gb/s channel is able to sustain at least 23-ps mean DGD for error-free operation, owing to strong digital processing in the coherent receiver. The results of this trial confirm the suitability of 111-Gb/s CP-QPSK for multi-rate operation in existing systems on presently-deployed fiber infrastructures.

**References**

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