

Record 579.5 km Unrepeated 2.5Gb/s Transmission with a Span Loss of 96.8 dB by Coherent Receiving Technology

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Abstract. In this work we experimentally demonstrate record 579.5km commercial unrepeated 2.5G transmission, with the first application of 2.5Gb/s polarization multiplexed quadrature phase shift keyed (PM-QPSK) format combined with a coherent receiver. Such ultra-long haul is enabled by use of Forward Error Correction(FEC), PM-QPSK transponders, ultra-low loss (ULL) fiber, and optimization of remotely pumped optical amplifiers (using forward RGU and backward RGU). To the best of our knowledge this is the longest unrepeated 2.5G-based transmission distance reported to date.

Key words: Unrepeated transmission, PM-QPSK, coherent receiver.

INTRODUCTION

As the optical fiber communication distance gradually extend, unrepeated transmission systems have proven to be a cost-effective solution compared to repeated solutions. Many ultra-long-haul transmission lines are deployed across hostile geographical areas (e.g., high mountain ridges, deserts, subsea links ...) where positioning repeater stations would prove to be impractical and cost prohibitive. Unrepeated transmission technologies significantly reduce the cost of long distance transmission due to the fewer number of O-E-O repeater sites [1-4]. Ultra-long span optical transmission systems provide a powerful guarantee for network security, stability and economic operation.

With the application of powerful FEC coding, Raman pumping, ROPA and ULL fiber (G.652), the commercial 2.5G ULH systems could achieve transmission over 500 km. In a laboratory environment, ultra-low loss fiber with large effective area (G.654) and ROPAs with dedicated pumping fibers could improve transmission span to 570 Km. However ultra-low loss fiber with large effective area has not been commercial used for the expensive price compared to ULL fiber (G.652). As the dedicated fiber only serve to convey pump power, and do not carry any traffic, this ULH systems are limited by the number of fibers.

In this paper, we demonstrate a 2.5Gb/s unrepeated transmission over 579.5 km (96.8 dB), with ULL fiber, second-order Raman pumping and two ROPAs on the line (one is located at transmitter end and the other is located at receiver end). This record distance is achieved with a single fiber for both the signal and pump propagation. 2.5G PM-QPSK format associated with coherent receiver is first employed for its improved OSNR sensitivity and its power tolerance. The optimum ROPA configuration with second order Raman pumps is also studied. These results are obtained through the use of a commercially available line terminal equipment with distributed Raman pump modules, PM-QPSK transponders and 2.5G coherent receive technology. To the best of our knowledge, the results shown in this work are the longest unrepeated distances reported to date of 2.5Gb/s [5-6],

EXPERIMENTAL SETUP

The experimental setup is shown in FIG.1. The setup is configured to transmit 2.5G at 1550.12 nm. The 2.5Gb/s signal is NRZ-PM-QPSK modulated at 2.67Gb/s which accounts for the 7% overhead of the Hard-Decision Forward Error Correction (HD-FEC) code. The HD-FEC can correct a BER of $8.0E-04$ to less than $1.0E-15$ (NCG of 8dB). The signal is amplified through Erbium-doped Fiber Amplifier (EDFA) after a Tunable Dispersion Compensation Unit (TDC). Wavelength Division Multiplexing (WDM) is used to multiplex the signal and pumping power which realize distributed Raman amplification in the transmission fiber and provide residual pumping power for Remote Gain Unit(RGU). The pump modules at transmitter end and receiver end include four wavelengths ranging between 1420 and 1500 nm. At the transmit side, approximately -960 ps/nm of dispersion pre-compensation is placed before the EDFA to improve transmission performance for 2.5G transmission. At the receive end, the signal is amplified by an EDFA within a filter of 100GHz pass-band to filter out the ASE from the EDFA. At the last the signal with appropriate power is sent to 2.5G coherent receive module which is in charge of decoding, DSP processing and so on.

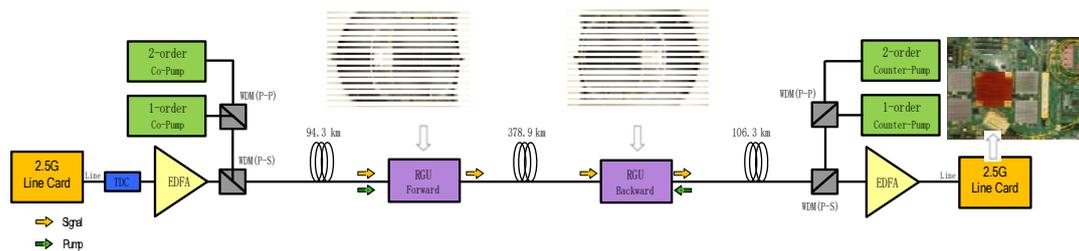


FIG.1. Experimental setup for 579.5km unrepeated transmission.

The span is assembled with ULL optical fiber. The forward and backward RGUs are located at 94.3 km and 106.3 km from the terminals, respectively. The distance between the RGUs is adjusted to 378.9 km for a total span length of 579.5km, and a span loss of 96.8 dB (loss of the RGUs not included), resulting in an average fiber (including splices and connectors) loss of 0.167 dB/km. The span distance and the loss are carefully verified by OTDR measurement and direct loss measurement with an Optical Power Meter. The yellow and green arrows in FIG.1 represent signal and residual pumps.

Second-order Raman amplification technology is applied at both ends of the link. The longest wavelength in both the forward and backward pump modules is primarily used to excite the RGUs. The launched pump power of the forward and backward Raman pump modules is 2400 mW and 2500 mW at 1360 nm. Along the transmission line, this 1360 nm pump power is converted into 1480 nm pump power through the 2-order Raman amplification process thus providing Raman gain for the signal. For performance of both of the forward and backward RGU, pump from the terminals plays a vital role. The forward RGU has bigger pump power but operating in the strong signal amplification regime, the backward RGU is operating in the weak signal amplification regime but with smaller pump power. As Remote Amplifier is a dynamic optical amplifier, so the best position and optical design of RGU can maximize the OSNR of the system. The gain and noise figure for forward RGU and backward RGU were measured at the same on FIG.2, which are important for designing of optical structure of RGU and choosing the position of RGU.

According to ITU - T REC G. 692 and equivalent noise figure expression of ROPA system, FIG. 3 shows test curve between gain and noise figure of RGU with system OSNR. We can see that under the condition of small gain, gain of RGU has a greater impact on OSNR of system; the improvement of OSNR is not very obvious when the gain reaches a certain value, therefore, in the case of small change for gain of RGU, we should give priority to select the RGU which has lower noise figure when designing remote gain unit.

For the ULL transmission fiber, the attenuation on pump wavelength is estimated to be 0.190 dB/km, and the attenuation on signal wavelength is 0.167 dB/km. We assume that the main contributions to OSNR are coming from backward RGU, and the impact of Amplified Spontaneous Emission (ASE) noise from forward RGU is neglected. The optimum position of RGU is calculated using the experimentally obtained values for EDFA noise figure (6 dB), Raman gain (28 dB) and Raman noise figure (-2.3 dBm). According to the calculated result, the optimum position of

forward RGU is 95 Km away from the transmitter end, and the backward RGU should be placed 105Km away from the receiver end.

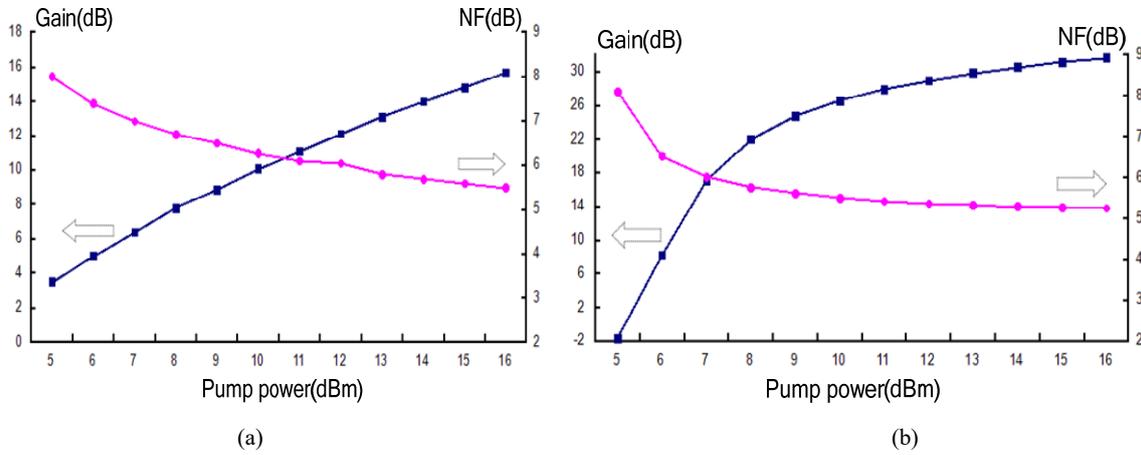


FIG.2. (a) Measured gain and noise figure of forward rgu, input optical power is -4dbm; (b) measured gain and noise figure of backward rgu, input optical power is -40dbm. all measurements are performed for 193.4thz channel.

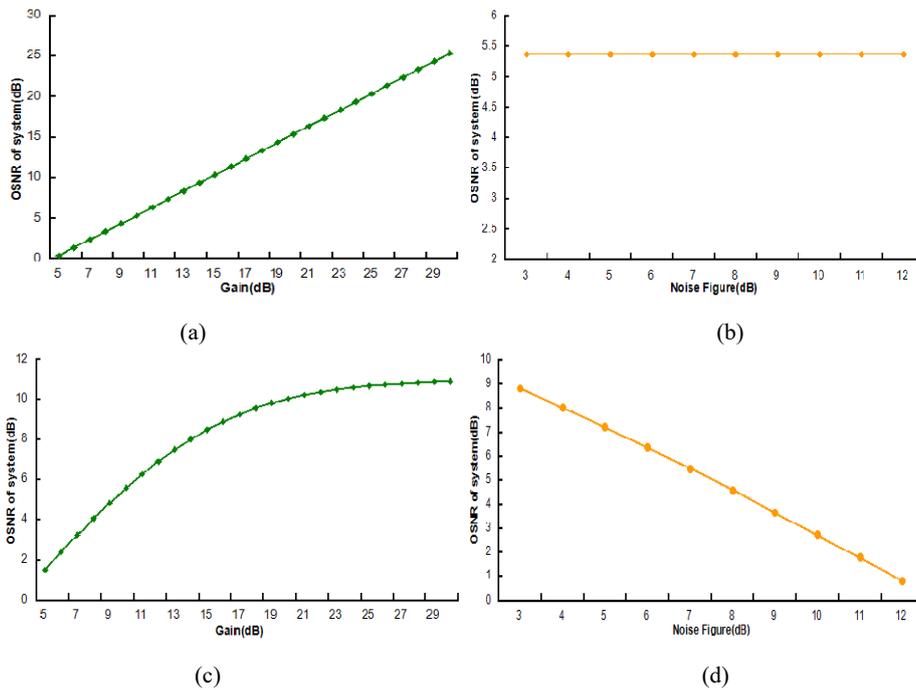


FIG.3. (a) Relation curve between gain of forward rgu with system osnr; (b) relation curve between nf of forward rgu with system osnr; (c)relation curve between gain of backward rgu with system osnr; (d)relation curve between nf of backward rgu with system osnr.

TRANSMISSION RESULTS AND DISCUSSION

Figure 4(a) shows the simulated power profiles for a single channel signal power and associated Raman pump power distributions along the 579.5 km span. The signal first experiences the forward distributed Raman amplification. Then the signal is amplified by the forward RGU, attenuated by the fiber of the second span, and

amplified again by the backward RGU. Finally, the signal experiences the backward distributed Raman amplification. The forward RGU gain is 6.6 dB, while the backward RGU provided 23.4 dB of gain to the signal. FIG 4(b) shows the measured spectrum at both the input and output of the span. The measured OSNR at the receiver is 2.37 dB, in very good agreement with the simulation (2.21 dB).

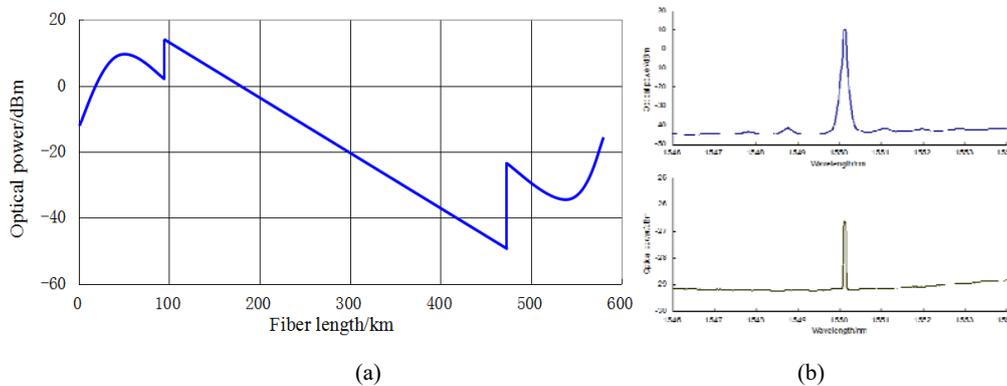


FIG. 4. (a) Simulated signal power distribution, output osa spectra of 579.5km transmission. (b)optical spectrum measured at the transmitter and receiver side.

To study the 2.5G SDH performance, we measured the bit error ratio (BER) of signal channel during the real-time transmission. The launch power into transmission fiber is optimized to minimize the pre-FEC BER difference during testing period. The real-time BER measurements over the course of 24 hours show excellent stability and are shown in FIG.5(a). The transponders used in this experiment employed hard-decision FEC, with the pre-FEC threshold of $8.0E-04$ (corresponding to a Q of 9.98 dB). Additionally, the absence of post-FEC errors on the client side is monitored using a BER-analyzer. Meanwhile, eye diagram is also described by offline processing method. FIG.5(b) showed the eye diagrams of four different points at the coherent receiver. The four pictures are eye diagram of the original sampling data, equalization of polarization demultiplexing, estimation of line-width and estimation of frequency offset as the arrow indicated.

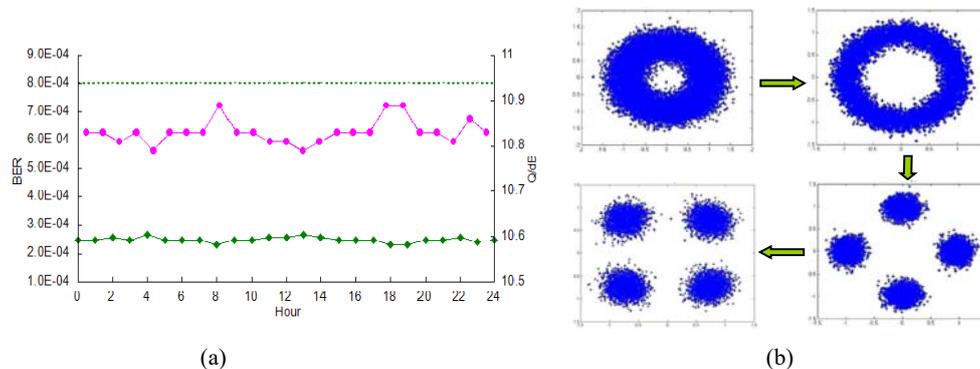


FIG.5. (a)24 hours ber test for 2.5g coherent system, left is ber, right is q. (b)eyes for four different points at the coherent receiver.

CONCLUSION

To the best of our knowledge, we have demonstrated for the first time 2.5G unrepeated transmission over 579 km distance with 2.5Gb/s PM-QPSK format combined with a coherent receiver, which is the longest unrepeated transmission ever demonstrated. Such record results are achieved by using a single fiber type, commercial Raman pump modules and 2.5G channel cards, providing a practical solution for real field deployments.

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