Single-Carrier 500Gb/s Unrepeatered Transmission over a Single 431km Span with Single Fiber Configuration

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Abstract: We demonstrate record single-carrier 500Gb/s unrepeatered transmission over a single span of 431km with single fiber configuration, using optimized high-order Raman pump, forward and backward ROPAs, and optimal modulation format while using the same single ultra low loss with large effective area fiber for both signal and pumps.

OCIS codes: 060.2330 fiber optical communications, 230.4480 Optical amplifiers, 060.1660 Coherent communications.

1. Introduction

Unrepeatered ultra long haul systems are widely used in submarine networks and ultra high voltage AC&DC power grid construction, which are beneficial to desert, depopulated, poor environment area. The goal of unrepeatered transmission systems is to bridge long distances without any in-line active elements, thus simplify the transmission line and reduce the line complexity and the overall system cost. It is quite challenging to increase the transmission distance in unrepeatered links, especially for high rate signal, such as 200G+ services. Over the past several years, 200G+ transmission experiments have been reported to increase the unrepeatered distances[1-5], thanks to the introduction of more powerful SD-FEC coding, ultra low loss and large effective area optical fiber, and optimized Raman/Remote Optically Pumped Amplifier (ROPA) architecture.

More recently, the bit-rate per wavelength has moved up to 200G+, thanks to the Polarisation Multiplexed Quadrature Amplitude Modulation (PM-QAM) modulation format combined with a coherent receiver which enabled high rate laboratory experiments: 108×200Gb/s PM-16QAM over 401km[1], 40×200Gb/s PM-16QAM over 363km[2], 16×400Gb/s PM-16QAM over 403 km[3], 24×400Gb/s PM-16QAM over 443km[4], 400Gb/s PM-64QAM over 502km[5]. These experiments used one or two dedicated pump paths, these dedicated fibers serve only to convey pump power, and do not carry any data traffic. It will be more attractive and cost effective if a simple single fiber configuration can be used to avoid the dedicated fibers.

Here in this paper, we report a record unrepeatered transmission reach of 431.77km at single-carrier 500Gb/s system, which offer the signal-carrier rate to be five times as much as rate compared to 100Gb/s PM-QPSK. The experiment applied forward and backward high performance high-order Raman pumps, optimization and tailor-made modulation format, and ultra low loss fiber with large effective area G.654E fiber used to reduce the attenuation and transmission non-linear effect at both the signal and pump wavelengths. To the best of our knowledge, this is the longest reach of 500Gb/s single span unrepeatered transmission in single fiber configuration.

2. Experiment setup

The experimental setup is shown in Fig. 1. The signal is PM-32QAM modulated at 70.99GBaud which accounts for the 27% overhead of the Soft-Decision Forward Error Correction (SD-FEC) code. The SD-FEC can correct a BER of 3.3E-2(Q=5.28dB)to less than 1.0E-15. At the transmitter side, the 500G signal is directly multiplexed into fiber line by IWDM(ISO+WDM). At the receiver side, an EDFA amplifies the received signals and a filter(100 GHz) is used to filter out the ASE from EDFA.

The forward and backward Remote Pump Units (RPU) consist of five pump wavelengths distributed in the range between 1300nm and 1500nm, The two wavelengths of third-order pump source (P1) operate in the range between 1300nm and 1400nm, the two wavelengths of second-order pump source (P2) operate in the range between 1400nm and 1450nm, and the wavelength of first-order pump source (P3) operates in the range between 1475nm and 1500nm, which realize Raman amplification for signal and provide residual pumping power for forward and backward Remote Gain Units (RGU). The signals first experience the forward Raman pumping gain, then they are amplified by the forward RGU and attenuated by middle fiber loss, the signals are amplified again by backward RGU, finally, they experience the backward Raman pumping amplification before reaching the receiver side.

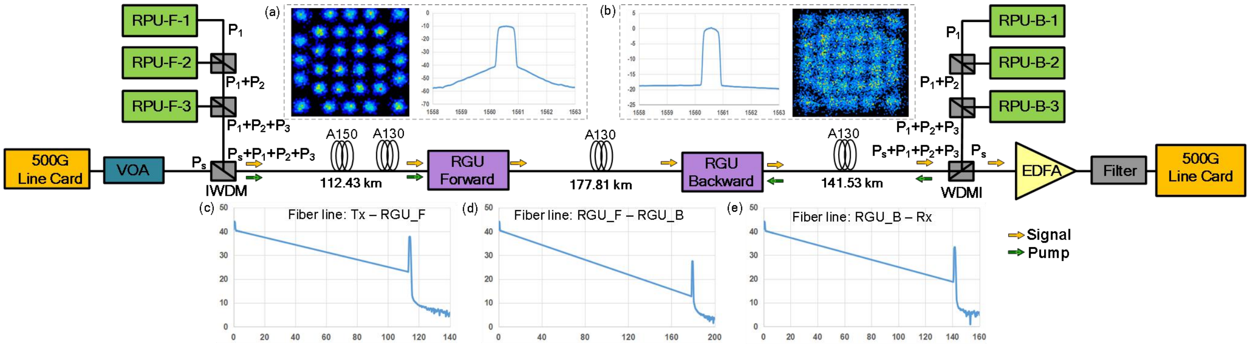

Fig. 1. Experimental setup for 500Gb/s transmission. Constellation map & spectrum measured at the transmitter(a) and receiver side(b). Fiber length of the three spans measured by OTDR: transmitter side to forward RGU(c), forward RGU to backward RGU(d), and backward RGU to receiver side(e).

The span is assembled with YOFC Farband® Ultra A150 and A130 optical fiber which has an average chromatic dispersion of 20.9ps/nm-km and effective area of 150μm^2 and 130μm^2 respectively[6]. The first section combines two types of large effective area fibers: A150 and A130 fiber. The A150 section of 100km is placed at transmitter side, to increase the nonlinear threshold compared to common A130 fiber. Higher signal and pump power can be launched into the transmission fiber by larger effective area fiber, which can be seen in figure. 2. Thank to large effective area fiber and forward RGU technology, high launched signal and pump power is realized, A130 and A150 fiber can increase of 1.6dB and 2.3dB compared with G.652 fiber, respectively. Compared with single EDFA technology to promote the launched signal power, forward single-core ROPA technology can increase equivalent launched signal power of 13.2dB, which can approximately extend the transmission distance of 80km.

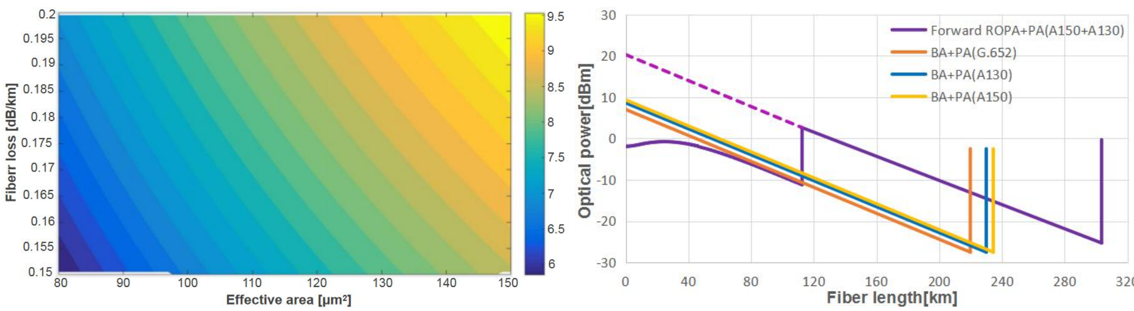

Fig. 2. Launched power into fiber as a function of fiber loss and effective area(left). Equivalent launched power into fiber with different optical amplifiers and fiber type configuration(right)

The transmission fiber link consists of three spans divided by the forward and backward RGUs. An coordinating and optimized RPU and RGU configuration are introduced in this trial. The forward RGU is located at 112.43km from the transmitter side, the backward RGU is located at 141.53km from the receiver side respectively. The middle span is adjusted to 177.81km for a total link length of 431.77km and loss of 67.78dB at 500Gb/s (losses of the ROPAs are not included), resulting in an average fiber loss (including splices) of 0.157dB/km at 1560.61nm. The accumulated chromatic dispersion is approximately +9000ps/nm at the signal wavelength. As shown in Fig.1, all the fiber lengths are verified by OTDR, and the loss is carefully measured by Optical Spectrum Analyzer(OSA).

3. Transmission results and discussion

The best performance requires multidimensional optimization of the signal modulation format, launched signal power, optical structure of RGUs, forward and backward pump wavelengths and powers. As shown in Fig. 3, PM-32QAM is deployed to apply 500Gb/s instead of 64QAM, which has higher nonlinear tolerance. Fig.3(left) shows the simulated optical power profiles of 500Gb/s system based on measured launch signal powers, forward and backward pump powers , gain of forward and backward RGUs, and the characteristics of the transmission fiber, Figure. 3(right) shows the measured spectra at both the input and output of the span. The measured OSNR at the receiver was 25.85dB/0.1nm at 500Gb/s, the measurement was done with 0.067nm resolution using an EXFO OSA(FTB-5240S). The signal power launched in the fiber is -1.61dBm. The forward pump power launched at the transmitter side is 1960mW, and the backward pump power launched at the receiver side is 2280mW.

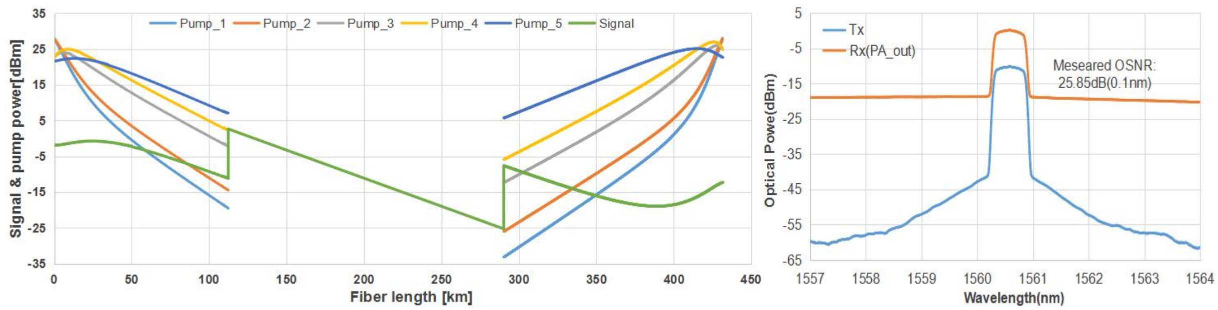

Fig. 3. Signal and pump power evolution along 431km fiber line(left). Input and output OSA spectra(right)

The residual pump powers reaching the RGUs were measured to be 4.89mW and 3.78mW for the forward and backward RGUs, respectively. The measured gain and NF of forward RGU and backward RGU are shown in Fig. 4(left), the forward RGU gain was 13.9dB, while the backward RGU provided 17.6dB of gain to the signal. A wavelength relation transmission test is performed in order to evaluate the optimum transmission quality versus wavelength, the wavelength of the 500Gb/s is tuned from 1554 to 1568nm, and the BER is measured for the different wavelengths. The results are shown in Figure. 4(middle)， it can be noted that the best performance is achieved around 1560.61nm, where the fiber loss is low and the ROPA still provides sufficient gain. The results of a 24-hour stability test were recorded in Fig. 4(right). This long-term measurement shows excellent stability of the 500Gb/s channel. The average and max pre-FEC BER over the duration of the test were 3.07E-2(Q = 5.42dB) and 3.1E-2(Q = 5.38dB), and no uncorrected errors were observed after SD-FEC.

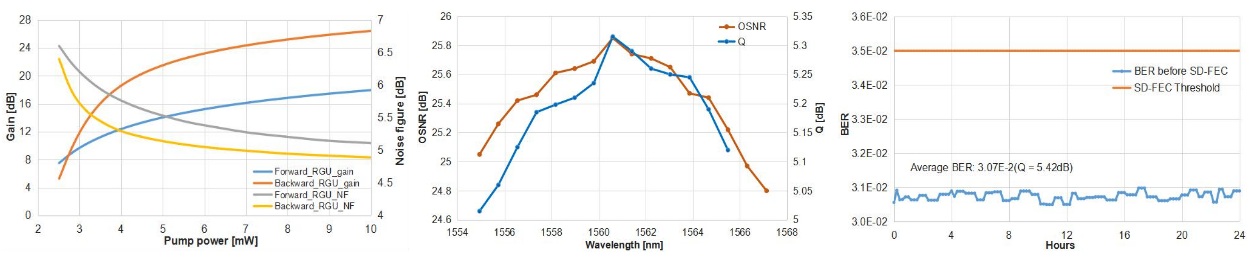

Fig. 4. Gain and NF for forward and backward RGU (left). OSNR and Q at different wavelengths(middle). Stability measurement over 24hours at 500Gb/s(right)

4. Conclusion

We demonstrated recorded unrepeatered transmission of single-carrier 500Gb/s over 431.77km with 67.78dB span loss with single fiber configuration, this is the new span distance ever reported for an unrepeatered transmission in single-carrier 500Gb/s. The line includes one forward RGU at the transmitter side and one backward RGU at the receiver side， and no electric power supplied devices are placed at the whole fiber line. Such recording result are achieved by using high performance Raman pumping configuration, innovative RGUs, optimization and tailor-made modulation format, ultra low loss and large effective area fiber.

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References

[1] Yue-Kai Huang et al. “20.7-Tb/s Repeater-less Transmission Over 401.1-km Using QSM fibre and XPM Compensation via Transmitter-side DBP,” Proc. ECOC, PD1-4(2016)
[2] H. Bissessur et al. “8 Tb/s unrepeatered transmission of real-time processed 200 Gb/s PDM 16-QAM over 363 km,” Proc. ECOC, Tu.1.5.3(2014)
[3] Joao C.S.S. Januario et al. “Unrepeatered WDM Transmission of Single Carrier 400G (66-GBd PDM-16QAM) over 403 km,” Proc. OFC, Th4D.1. (2017)
[4] Joao C.S.S. Januario et al. “Single-Carrier 400G Unrepeatered WDM Transmission over 443.1 km,” Proc. ECOC, M.1.F (2017)
[5] Jian Xu et al. “50G BPSK, 100G SP-QPSK, 200G 8QAM, 400G 64QAM ultra long single span unrepeatered transmission over 670.64km, 653.35km, 601.93km and 502.13km respectively,” Proc. OFC, M2E.2 (2019)
[6] Lei Zhang et al. “Novel Ultra Low Loss & Large Effective Area G.654.E Fibre in Terrestrial Application,” Proc. OFC, W2A.23 (2017)