# 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

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**Abstract:** We demonstrates record single-carrier 50Gb/s, 100Gb/s, 200Gb/s and 400Gb/s unrepeatered transmission over 670.64km, 653.35km, 601.93km and 502.13km respectively. Using optimized Raman amplifiers, cascaded RGUs, ultra low-loss & 130-μm$^2$ $A_{eff}$ fibers, and optimal modulation format. 

**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 (UHV) ac 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.

The current deployments of unrepeatered systems apply 100 Gb/s, 200Gb/s and 400Gb/s per wavelength thanks to the polarization division multiplexed, phase shift keying modulation format combined with a coherent receiver. So far, several articles have reported unrepeatered transmission distance at 100G, 200G and 400G [1-4]. Fig.1 shows a summary of recorded unrepeatered transmission distance with different system channel bit rate. At 100Gb/s, forward and backward Remote Optically Pumped Amplifiers (ROPA) were used to achieve 626.8km transmission reach [1]. 16 QAM multi-level modulation at 200 Gb/s offers the potential to double the overall capacity compared to 100 Gb/s QPSK, unrepeatered experiments based on the200 Gb/s PDM-16QAM modulation format have been recently reported over 401.1km with 108 transmitted channels [3], the longest 400Gb/s unrepeatered transmission in single-carrier was achieved over 443.1km, employing large-effective area low-loss fibers and ROPA [4].

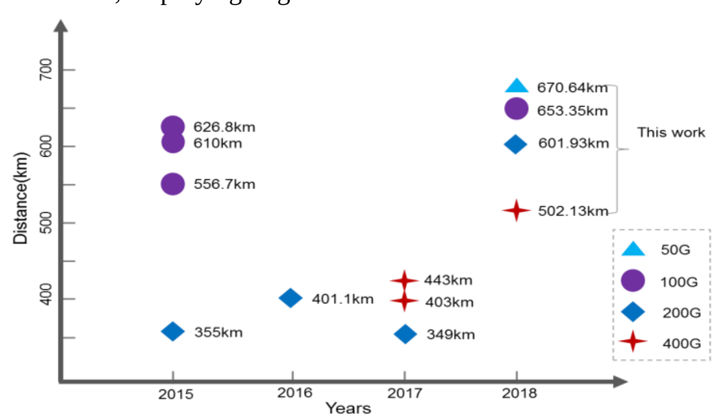


Fig.1. Record unrepeatered transmission distance with different system channel bit rate.

Here in this paper, we report a record unrepeatered transmission reach of 670.64km at 50G, 653.35km at 100G, 601.93km at 200G, and 502.13km at 400G system, applying forward and backward high performance Raman pumping, optimization and tailor-made modulation format at the transmit and receive terminal, innovative cascading remote gain units(RGU) which is placed in the position of 175.61km from the receive side, and large effective area G.654E fiber. It has proven that the key parameters of ultra low loss and large effective area can provide higher incident power, lower link attenuation and longer transmission distance [5].

## 2. Experiment setup

The experimental setup is shown in Fig. 2. The setup is configured to transmit 50G, 100G, 200G and 400G at 1563.05 nm, an integrated coherent card (NOKIA Bell) enables the generation of a multi-codes signal, which generate BPSK (a in Fig. 2), SP-QPSK (b in Fig. 2), 8QAM (c in Fig. 2) and 64QAM (d in Fig. 2) for 50G, 100G, 200G and 400G respectively. The concatenated FEC (a soft-decision FEC followed by a hard-decision FEC) can correct a BER of 3.3E-02 (Q=5.28 dB) down to less than 1.0E-15. At the transmit side, a pre-dispersion compensation unit (DCU) is placed at the front of the EDFA to improve transmission performance for both 50G, 100G and 200G. The optimized DCU values of -2647 ps/nm for 50G, 100G and 200G operation. 100GHz pass-band filters are used to filter out the ASE from EDFA and Raman at the transmit and receive side.

The span is assembled with YOFC Farband® Ultra A130 optical fiber which has an average chromatic dispersion of 19.8 ps/nm-km and effective area of 130 $\mu m^2$. The transmission fiber link consists of four parts divided by the three RGUs. The forward RGU are located at 131.1 km at 50G and 100G, 142.9km at 200G and 400G from the transmit side. The first and the second backward RGUs are all located at 175.61km and 126.58 km from the receive side respectively. The middle span is adjusted to 363.93 km for a total link length of 670.64 km and loss of 103.95dB at 50G, 346.64 km for a total link length of 653.35 km and loss of 101.27dB at 100G, 283.42 km for a total link length of 601.93 km and loss of 93.3dB at 200G, and 183.62 km for a total link length of 502.13 km and loss of 77.83dB at 400G (losses of the ROPAs are not included), resulting in an average fiber loss (including splices) of 0.155dB/km at 1563.08nm. The dedicated pump paths use the same fiber length of the signal paths. As shown in Fig.2, all the fiber lengths are verified by OTDR, and the loss is carefully measured by optical spectrum analyzer (OSA).

All distributed Raman pump modules use the same high-order Raman amplification technology. The 1st order pump modules of both transmitter and receiver side have 2 wavelengths ranging from 1450 nm to 1500 nm to realize Raman amplification for signal and provide residual pumping power for RGUs. The signal paths and dedicated pump paths use different 1st order pump wavelength, so that all the residual pumping power can be coupled into RGUs. The signal paths turn off the longest wavelength, which provide more efficient Raman gain to the signal wavelength and help to reduce the RIN transfer penalty. The high order pump modules have 4 wavelengths ranging from 1300 nm to 1450 nm to realize Raman amplification for 1st order pump wavelengths [6]. Both the pump and signal wavelengths are multiplexed and launched into the transmission fiber. EDFA-BA is only used to amplify the signal at the transmit terminal for 400G because low nonlinear threshold is borne for 64QAM and high baud rate.

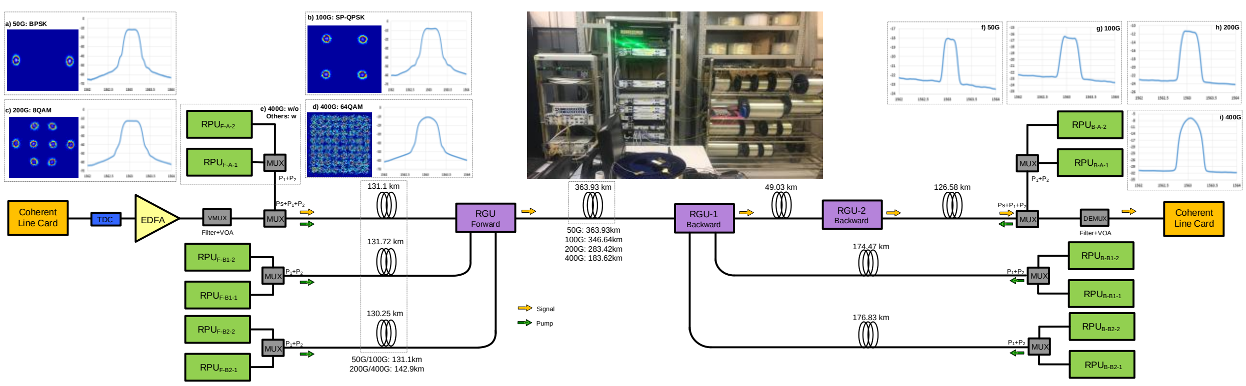


Fig. 2. Experimental setup for 50G, 100G, 200G and 400G transmission. Constellation map & spectrum of 50G (a), 100G (b), 200G (c), 400G (d) measured at the transmit side; 670.64-km, 653.35-km, 601.93-km and 502.13-km transmission spectrum measured at the coherent receiver for 50G (f), 100G(g), 200G(h) and 400G(i), respectively.

## 3. Transmission results and discussion

The best performance requires collective optimization of the signal modulation format launch power, forward and backward pump powers. As shown in Fig.3, SP-QPSK is deployed to apply 100G instead of QPSK, and 8QAM is deployed to apply 200G instead of 16QAM which has higher nonlinear tolerance because of broad spectrum. Fig.4(left) shows the simulated optical power profiles of 50G, 100G,200G and 400G based on measured launch signal powers, forward and backward pump powers and the characteristics of the transmission fiber, the signal power launched in the fiber is -6.19dBm, -3.32dBm, -2.26dBm and 7.27dBm at 50G, 100G, 200G and 400G transmission respectively. The forward signal path pump power launched at the transmitter side is 2692mW for 50G, 2405mW for 100G and 2025mW for 200G transmission, the backward signal path pump power launched at the transmitter side is 2764mW for 50G, 100G and 200G, 2123mW for 400G transmission which indicate the 400G system has a worse nonlinear tolerance. The same dedicated pump paths pump power of 2835mW is used for 50G, 100G, 200G and 400G. The residual pump powers reaching the forward RGU are 7.31mW, 6.01mW, and 3.43mW from signal path at 50G, 100G and 400G respectively, 12.53mW for 50G and 100G, 8.13mW for 200G and 400G from the first pump path, 12.61mW for 50G and 100G, 8.29mW for 200G and 400G from the second pump path. The residual pump powers reaching the first backward RGU are 1.99mW from the first pump path and 2.01mW from the second pump path.

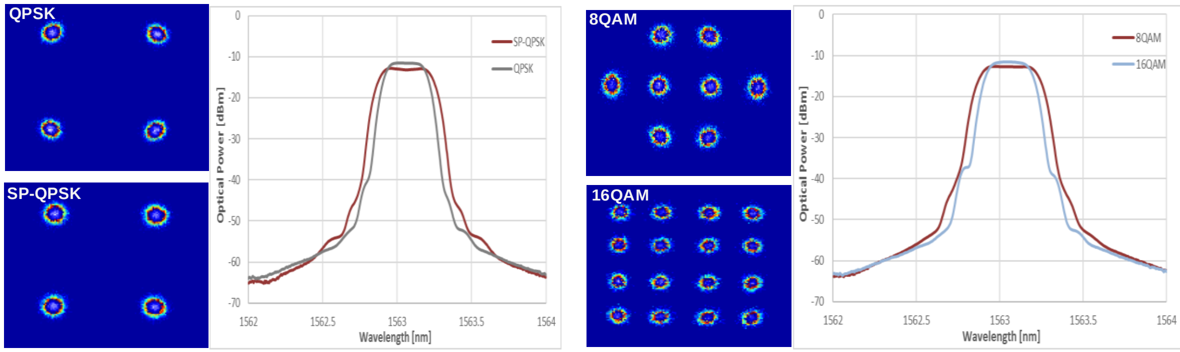


Fig. 3. Constellation map and spectrum of QPSK and SP-QPSK at 100G (left), 8QAM and 16QAM at 200G (right)

The three RGUs were designed based on the optimization EDF classification and optical path length for different transmission system, and innovative cascading RGUs were first applied to enable the first backward RGU to be placed at further position from the receive side, 2.9dB OSNR improvement will benefit the system at the same pump power, compared with single RGU, as shown in Fig.2(middle). The spectrums at the receiver side were shown in Fig.2. The OSNR of the signal channel is 7.49dB/0.1nm at 50G (f in Fig.2), 10.91dB/0.1nm at 100G (g in Fig.2), 17.39dB/0.1nm at 200G (h in Fig.2), and 28.8dB/0.1nm at 400G (i in Fig.2). The average pre-FEC BER over the duration of the test were 2.69E-02 at 50G, 2.34E-02 at 100G, 2.19E-02 at 200G and 3.04E-02 at 400G. The results of a 16-hour BER stability test were recorded in Fig.4(right). Additionally, the absence of post-FEC errors on the client side was monitored using a BER-analyzer.

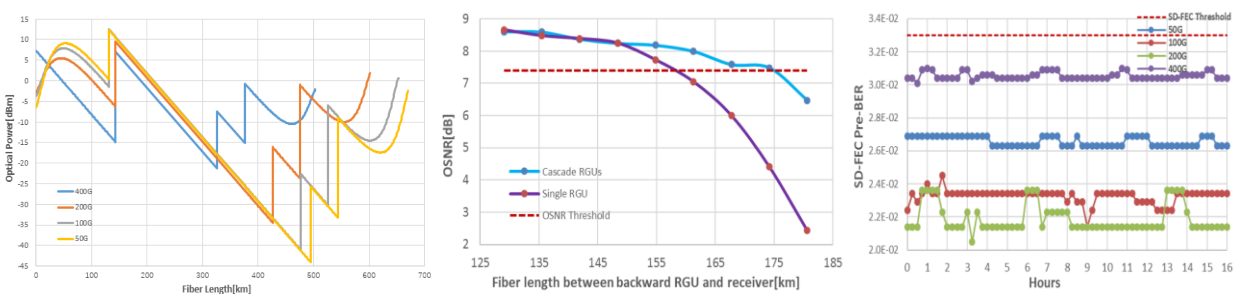


Fig. 4. Simulated signal power distribution (left). OSNR comparison between cascade RGUs and single RGU (middle). Stability measurement over 16hour at 50G, 100G, 200G and 400G.

## 4. Conclusion

We demonstrated unrepeatered transmission of single-carrier 50Gb/s over 670.64km with 103.95dB span loss, 100Gb/s over 653.35km with 101.27dB span loss, 200Gb/s over 601.93km with 93.3dB span loss, and 400Gb/s over 502.13km with 77.83dB span loss. These are the new span distance ever reported for an unrepeatered transmission in single-carrier 50G, 100G, 200G and 400G, with the first application of single-carrier 50Gb/s PM-BPSK format in single-core unrepeatered transmission. Such recording results are achieved by using high performance Raman pumping configuration, innovative cascading RGUs, optimization and tailor-made modulation format, ultra low loss & large effective area fiber.

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