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Abstract. An 112 Gbit/s real-time coherent passive optical network downlink transmission experiment over 100 km standard single mode fiber with 1:128 splitting ratio is demonstrated. Adaptive dispersion compensation digital signal processing in the real-time receiver has compensated 100 km dispersion and 50 km dispersion difference with almost no power penalty and 43.5 dB power budget has been achieved. [DOI: 10.1117/1.OE.51.4.040505]

Subject terms: passive optical network; coherent detection; polarization multiplexing; quadrature phase shift keying; power budget.

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1 Introduction

Passive optical networks (PONs) are widely being installed for broadband access networks. Driven by both exponentially growing demand for broadband services and standardization activities, next-generation PONs with high capacity, long reach and aggressive power budget are becoming the hot research topic in the near future.[1–3] For higher data rate, e.g., 40 Gbit/s or 100 Gbit/s, it is well known that fiber dispersion [chromatic dispersion (CD) and polarization mode dispersion (PMD)] is a severely limiting factor of transmission distance,[4] Hence, compensation of different fiber dispersion due to different fiber length from optical line terminal (OLT) to optical network units (ONUs) becomes necessary for point-to-multipoint PONs. At the same time, it is also important to decrease the total cost of power budget which can afford longer transmission distance and a higher splitting ratio.

As it can support the phase modulation, such as quadrature phase shift keying (QPSK) or M level quadrature amplitude modulation (M-QAM), coherent detection is an attractive solution for the requirement of high capacity, long reach and big splitting for next generation passive optical network (NG PON). Although the coherent detection technology is not currently widely used in PONs, it will be employed generally in the high-speed PONs in the near future, as it has already been widely used in backbone networks already. Dispersion compensation can be performed in the digital domain, and the receiver sensitivity can be significantly improved if the coherent detection is employed at receiver.[5,6] Meanwhile, polarization multiplexing (PM) combined with multi-level modulation formats could be employed to reduce symbol rate, with a result of reducing the sampling rate of analog-to-digital coverter (ADC). Five Gbit/s coherent detection PON transmission experiment over 40 km standard single mode fiber (SSMF) and 1:1024 optical split was reported this year,[7] but the bit rate of 5 Gbit/s is too low for NG PON's high-capacity requirement. Moreover, in order to obtain enough big power budget for NG PON and keep optical distribution network (ODN) passive, the impact of fiber nonlinearity on launched power needs to be investigated.

In this paper, we have experimentally demonstrated 112 Gbit/s PM-QPSK real-time coherent PON downlink transmission over 100 km SSMF with 1:128 optical split. Fiber dispersion is compensated in the digital domain at the receiving end, and the sensitivity penalty brought by dispersion compensation is about 0.2 dB. Due to the influence of fiber nonlinearity, the optimal launched power for biggest system power budget is found as 12.1 dBm or so, and the corresponding receiver sensitivity is −31.4 dBm at BER = 1.0E-3.

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2 Experimental Setup

Figure 1(a) depicts the experimental setup for 112 Gbit/s real-time coherent PON downlink transmission, including OLT, ONUs and tree-like ODN.

The structure of the OLT transmitter is shown in Fig. 1(b). A 13 dBm output power external cavity laser (ECL) with 1550 nm wavelength and 100 kHz line-width is employed as the optical source of the transmitter. Each of two in-phase/quadrature (I/Q) modulators consists of two Mach-Zehnder (MZ) modulators, which are modulated by two 28 Gbit/s I/Q electrical signal to obtain QPSK optical signal, and are driven by one polarization of laser beam to achieve polarization multiplexing. Polarization beam splitter (PBS) is used to split the laser beam of ECL into two polarizations, and polarization beam combiner (PBC) combines signals from two I/Q modulators.

One of the real-time coherent receivers in ONUs is shown in Fig. 1(c). The polarization multiplexed QPSK optical signal is split into two branches with PBS, and then each branch is combined with a local oscillator (LO) laser in an optical 90-deg hybrid for I/Q separation. After being detected by photodiodes and sampled with ADCs, the digitized I/Q signals are then fed to a real-time digital signal processing (DSP) unit, which is responsible for transmission impairment compensations and data recovery, namely adaptive equalization, polarization de-multiplexing, clock synchronization, frequency offset compensation, and phase recovery.

At OLT transmitter output, a gain tunable erbium-doped fiber amplifier (EDFA) with 5 dB noise factor is employed to adjust the power into fiber to analyze the influence of fiber nonlinearity. Loss of 100 km SSMF and the insertion loss of fiber connectors is 19.53 dB. At each of the ONU receiver inputs, there is a variable optical attenuator (VOA) to adjust

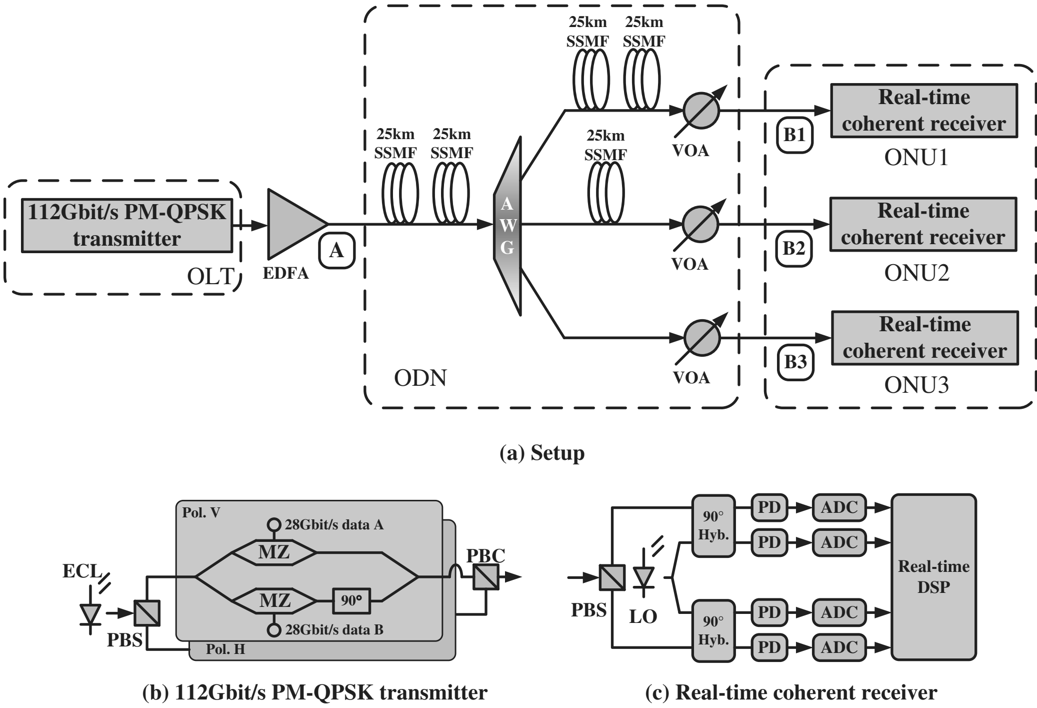


Fig. 1 (a) Experimental setup for 112 Gbit/s real-time coherent PON downlink transmission; (b) 112 Gbit/s PM-QPSK transmitter structure in OLT; (c) Real-time coherent receiver structure in ONUs.

the received power for sensitivity measurement or to simulate the loss corresponding to power-splitting. Point A and B (1,2,3) shown in Fig. 1(a) are four power monitoring points in the experiment.

3 Experimental Results

The measured bit error rate (BER) of the coherent system without EDFA and link transmission (B2B) is plotted in Fig. 2 together with the BER of the system with EDFA and 100 km SSMF transmission. Receiver sensitivity is −31.77 dBm at B2B condition, and almost the same sensitivities are acquired when EDFA is employed as power amplifier (−31.7 dBm). It means the 5 dB noise factor of the power amplifier is not a significant influence to the receiver sensitivity. When the signal is transmitted over 100 km SSMF (VOA is set at the output of EDFA to impress the influence of the nonlinear effect) with EDFA as power amplifier, receiver sensitivity is measured as −31.6 dBm. So, the sensitivity penalty brought by dispersion compensation is about 0.1 dB; meanwhile, the adaptive equalization algorithm of real-time DSP of the coherent receiver has a scope of compensation larger than 1700 ps/nm (corresponding to 100 km SSMF), and the compensation effect is superior.

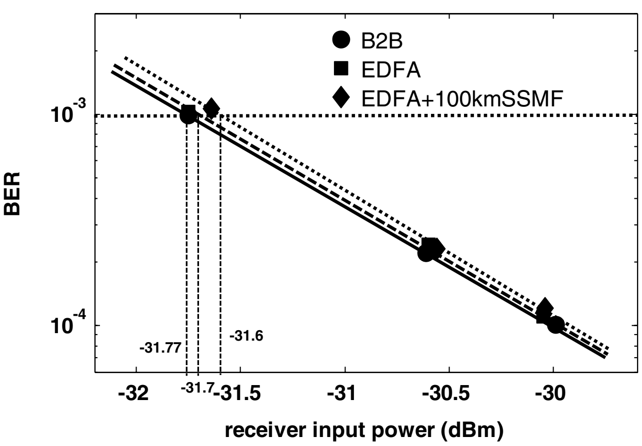
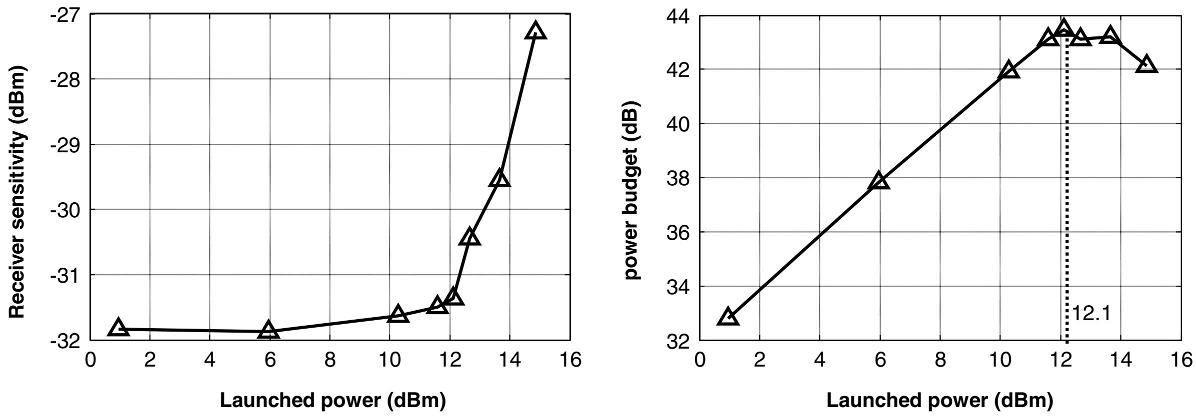


Fig. 2 BER versus receiver input power.

Figure 3 shows the relationship between the launched power of fiber link and the receiver sensitivity over 100 km SSMF transmission. Because of the influence of nonlinear effect, the sensitivity would worsen with launched power rising gradually, as is shown in Fig. 3(a). However, the power budget (the difference between launched power and receiver sensitivity) is a more important parameter in the PON system. Therefore, the optimal launched power is the point at which the deteriorating speed of receiver sensitivity is equal to the rising speed of the launched power. As shown in Fig. 3(b), when the launched power equals to 12.1 dBm, the biggest power budget, about 43.5 dB, can be obtained. That means the power budget stands for 43.5 dB loss comes from both fiber loss and branch loss in a PON system to satisfy the request of BER = 1.0E-3.

According to the above analysis, when launched power is set to 12.1 dBm, an 112 Gbit/s PM-QPSK coherent PON downlink transmission system over 100 km SSMF with 1 : 128 splitting ratio can obtain desirable BER performance smaller than 1.0E-3. Simulating the splitting ratio by 16.3 dB attenuator (total loss of arrayed waveguide grating (AWG) showed in Fig. 1 and attenuator is 21.1 dB, corresponding to 1 : 128 splitting ratio) at input of ONU1, we testify the analysis experimentally and the BER is 1.57E-4. We have



(a) (b)

Fig. 3 (a) Launched power versus receiver sensitivity over 100 km SSMF transmission; (b) Launched power versus power budget which is the difference between launched power and receiver sensitivity.

also experimentally investigated these two systems: 75 km SSMF with 1∶512 splitting ratio (set VOA to 22.3 dB at input of ONU2) and 50 km SSMF with 1∶1024 splitting ratio (set VOA to 25.3 dB at input of ONU3), the BER are 2.98 E-4 and 1.68 E-4, respectively.

4 Conclusions

We have experimentally demonstrated 112 Gbit/s PM-QPSK real-time coherent PON downlink transmission over 100 km SSMF transmission with 1∶128 optical split and supporting 50 km fiber length difference in PON. 43.5 dB power budget has been obtained under the impact of fiber nonlinearity in our experimental demonstration. This work has indicated that 112 Gbit/s PM-QPSK coherent PON is one of feasible solutions for high capacity, long reach and large scale next generation optical access networks.

Acknowledgment

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