Symmetric Bidirectional 200 Gb/s/λ PON Solution Demonstrated over Field Installed Fiber

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Abstract: We demonstrate 200 Gb/s/λ bidirectional coherent PON solution with simplified ONU on field installed fiber. We achieve 30.5/37 dB power budget for the downstream transmission with single-ended/balanced photodiode and 30.1 dB for the upstream transmission.

1. Introduction

Passive optical networks (PON) account for a large majority of optical access networks, allowing hundreds of millions of households and businesses to connect to the Internet. The continued deployment of these networks, coupled with the demand for increased bandwidth for future use require new solutions. The ITU-T has recently standardised Higher Speed PON (HS-PON) at 50 Gb/s [1], and has started preliminary work on Very High Speed PON (VHS-PON) [2], with an expected linerate of 100 or 200 Gb/s.

It is clear that intensity modulation with direct detection (IM/DD) will face significant challenges to reach higher rates than HS-PON, and for VHS-PON new technologies need to be investigated. There are some research investigations into 200 Gb/s IM/DD solutions [3, 4], however these require expensive components or digital signal processing (DSP) to reduce the penalties arising. Direct detection systems need to operate in the O-band, near the zero dispersion wavelength to minimise the chromatic dispersion. However, for PON the O-band is already very congested with legacy standards.

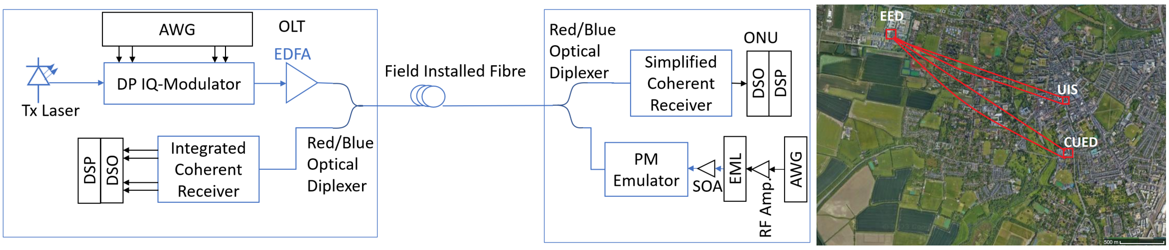
Coherent detections opens up clear improvements for the next PON standards, and easily meets the high power budget requirements of such system, and open up possibility of C-band operation. However, the cost of a traditional coherent receivers are much higher than the IM/DD system. These lead to extensive research on simplified coherent receivers and transmission technologies. The focus is simplifying the optical network unit (ONU) which is present at every individual end-user, for minimal system cost.

We have recently separately demonstrated both downstream [5] and upstream [6] at 200 Gb/s/λ linerate in lab experiment, with a simplified ONU architecture. Composing of single polarization heterodyne receiver, and dual polarization electro-absorbtion modulated laser (EML) based transmitter. In this paper, we show an integrated solution for symmetrical, bidirectional 200 Gb/s/λ PON. In addition, this work uses installed field fiber, achieving power budgets of 37/30.5 dB (for balanced detection and minimal coherent receiver) and 30.1 dB for downstream and upstream transmission, respectively. To the best knowledge of the authors, this represents the first installed fiber demonstration of 200 Gb/s/λ bidirectional, symmetric coherent PON.

2. Experimental Setup

The experimental setup revolves around three main components, as shown in figure 1a. The downstream transmission equipment, the upstream transmission equipment and the optical red/blue diplexer, that allows bidirectional transmission over single fiber. The downstream transmission uses an Alamouti-coded dual polarization 16 QAM signal at 50 GBaud. The transmitter is composed of an arbitrary waveform generator (AWG) operating at 100 GSa/s, followed by a commercial dual polarization IQ modulator with 3 dB bandwidth of 40 GHz. Digital predistortion is applied to the signal to mitigate transmitter impairments [5]. The signal is amplified by an EDFA to obtain optimum launch power, which is measured at the point of entry to the field installed fiber.

At the receiver for the downstream transmission a single polarization heterodyne receiver is used. There are two receivers investigated, one comprising of a 3 dB coupler and a balanced photodiode, and the other being the minimal coherent receiver, where the balanced photodiode is replaced by a single ended photodiode, achieving the minimum complexity required for coherent detection. The local oscillator (LO) power is 16 dBm. The receiver is built of discrete components, using a 70 GHz single-ended/balanced photodiode, and a 60 GHz RF amplifier. Digitization of the signal is obtained by an oscilloscope with 70 GHz bandwidth and 256 GSa/s. Signal processing is performed offline. First intermediate frequency (IF) is estimated and the signal is converted to baseband. Adaptive equalization is done by a decision directed least mean squares (DD-LMS) algorithm [7]. Chromatic dispersion



(a) (b)

Fig. 1. (a) Experimental setup for 19 km bidirectional transmission. (Arbitrary signal generator (AWG), optical line terminal (OLT), digital sampling oscilloscope (DSO), digital signal processing (DSP), electro-absorption modulated laser (EML), semiconductor optical amplifier (SOA), optical network unit (ONU)). (b) Geographical connection of field installed fiber (Electrical Engineering Division Building (EED), Cambridge University Engineering Department (CUED), University Information Services (UIS))

compensation is integrated into the adaptive equalizer.

The upstream transmission aims to minimize the cost at the transmitter. The 200 Gb/s linerate is realised using polarization multiplexed PAM-4 signals. The transmitter uses an integrated EML package. Due to equipment availability, the polarization multiplexed signal is emulated split-delay-combine technique [8] for decorrelated signals. However dual-polarization EMLs can be integrated in a single chip [9]. The launch power is set by an SOA, as it is more affordable and easier to integrate than EDFA, making it a better solution for the ONU. Similarly to downstream, the power is measured at the input to the field installed fiber. At the receiver side, a class 40 integrated coherent receiver (ICR) is used, with LO power of 16 dBm. The signal is captured using an oscilloscope with 70 GHz 3 dB bandwidth and 256 GSa/s. The signal is processed offline. The DD-LMS algorithm is used for adaptive equalization, and for better sensitivity, maximum likelihood sequence estimation (MLSE) with memory length of 2 symbols is utilized.

The bidirectional use of fiber is important for PON application. To minimize the losses while keeping the cost low, an optical red-blue diplexer [10] is used. This allows for a low insertion loss (0.7 dB) whilst keeping the cost lower than a circulator would permit. The field installed fiber is 19 km long and a part of the interconnect network of buildings at the University of Cambridge. The connections are between the Electrical Engineering division building, the main building of the Department of Engineering in the center of the city and one of the University Information Services server rooms. A geographical representation can be seen in figure 1b.

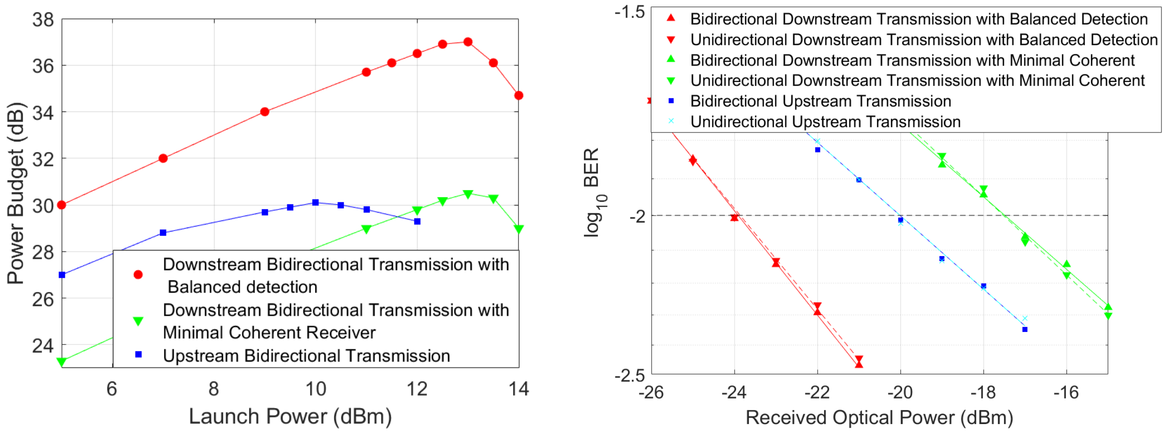
3. Results and Discussion

Evaluating the system performance is accomplished by measuring transmission sensitivity at the bit error rate (BER) threshold of 10^{-2}. The bidirectional transmission sensitivities for each launch power are measured while the other direction is operating at optimum launch power. For downstream transmission the optimum launch power was found to be 13 dBm. This is 2 dB more than the optimum in lab environment for our equipment [5]. The cause of this is the larger losses of the field installed fiber at a total loss of 12.7 dB for the 19 km fiber. This allows higher launch powers, as the nonlinear effects are less present. Power budget is presented in figure 2a. At optimum launch power the sensitivity was found to be -24 dBm, as can be seen in figure 2b. To evaluate the possible penalties arising from bidirectional use of the fiber, the optimum launch power measurement was repeated with the upstream transmission turned off. As it can be seen from figure 2b, there is no penalty observed, due to large wavelength separation between red and blue band.

The power budget observed at 37 dB is far in excess of ITU-T requirements, exceeding E2 class by 2 dB. This large margin affords lowering the launch power, or the LO power at the receiver, which should allow the solution to be even more cost effective. SOA may also be used in place of the EDFA, as the margin in power budget should allow for meeting the requirements despite the increased noise figure and pattering related penalties.

The minimal coherent receiver was also investigated as a downstream receiver. Here, sensitivity degradation is observed due to the inherent 3 dB penalty caused by using a single port on the 3 dB coupler and excess penalty due to the lack of common mode noise cancellation, mainly arising from LO relative intensity noise (LO-RIN). The sensitivity at optimum launch power was measured to be -17.5 dB, leading to a power budget of 30.5 dB for the system as shown in figure 2. This is still in excess of ITU-T N1 class specification,and hence suitable for PON.

The experiment was carried out in a similar manner for the upstream transmission. Here the optimum launch power was found to be 10 dBm. This is due to the limitation of the SOA used in the experiment, as at higher output powers gain compression occurs, which reduces transmission quality. This effect can be seen from the sensitivity degradation starting at 9 dBm launch power. The sensitivity at the optimum launch power is -20.1



(a) (b)

Fig. 2. (a) Power budget curves for the downstream and upstream transmissions. (b) Sensitivity curves at optimum launch power (13 dBm for downstream and 10 dBm for upstream transmission) in both bidirectional and unidirectional mode

dBm, as it can be seen in figure 2b. The maximum power budget achieved is 30.1 dB, which exceeds the 29 dB target of ITU-T N1 class transmission. The full curve is shown in figure 2a.
Unidirectional transmission was also performed to evaluate any penalties arising from interference from the other optical signal. The sensitivity curve remains the same for this transmission mode, as shown in figure 2b.
These results show the viability of the system and give a choice between ultra simple ONUs, using the minimal coherent receiver for the downstream to even further reduce cost, or trading some cost off for a significant (6.5 dB) gain in power budget when moving to the balanced photodiode based single polarization heterodyne detection.

4. Conclusions

To the best of the authors knowledge this represents the first symmetric, bidirectional 200 Gb/s/λ coherent PON solution demonstrated over field installed fiber. We achieve 37 dB power budget (30.5 dB if minimal coherent receiver is used) in the downstream transmission using 50 GBaud Alamouti coded 16 QAM signal. The upstream transmission achieves 30.1 dB power budget using 50 GBaud PDM-PAM4 signal. These power budgets exceed the ITU-T E2 and N1 class power budgets respectively and show the viability of coherent PON for next generation access systems.

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