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Tafur Monroy, Idelfonso ; Kjær, Rasmus; Jeppesen, Palle; Palsdottir, B.; Koonen, A.M.J.

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Idelfonso Tafur Monroy (1,2), Rasmus Kjær (1), Bera Palsdottir (3), A.M.J. Koonen (2), Palle Jeppesen (1)
1: COM●DTU, Department of Communications, Optics and Materials, DK-2800 Kgs Lyngby, Denmark
2: COBRA Institute, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands
3: OFS Fitel Denmark, Priorparken 680, DK-2605 Brøndby, Denmark

Abstract *We report operation of a single fibre bidirectional 80 km long reach PON link with symmetric up-and-downstream data rate of 10 Gb/s supported by distributed Raman fibre amplification only.*

Introduction

Long reach access networks have been proposed as a promising way to reduce the unit cost of bandwidth in fibre to the customer premises solutions [1-4]. The underlining idea behind the long reach access network is to use a high split passive optical network (PON) architecture with high capacity and extended reach (over 100 km) to merge optical access and metro networks into a single system [1,3,4]. In this way, the expectation is to reduce the amount of network elements, equipment interfaces and network nodes. Systems with symmetric up-and-downstream signals with bit rates up to 10 Gb/s and with split factors up to 1024 have been reported with link lengths up to 135 km by using optical amplification [1-4], dispersion compensating fibre [2] and super forward error correction and electronic dispersion compensation techniques [3], among others. The backhaul link of the above systems uses two fibres; one each for upstream and downstream communication between the core node (or service node) and the local exchange (or central office). We report on a long reach access system whose backhaul link is composed of a single fibre by introducing bi-directional communication and supported by distributed Raman fibre amplification. The experimental results show the feasibility of a 10 Gb/s symmetric up-and downstream bidirectional 80 km long backhaul link supported by distributed Raman amplification only with a power penalty below 0.7 dB.

Bidirectional backhaul link with distributed Raman fibre amplification

Our proposed single fibre, bidirectional, long reach backhaul link is depicted in Figure 1. The optical termination line (OTL) is connected to a metro core node. The backhaul link of a long reach PON system has a length of ~ 50-100 km and delivers signals to the local exchange where by using dense wavelength division multiplexing (DWDM) channels are further distributed to the splitting points at the access part of the network. Distributed Raman fibre amplification (DRFA) is introduced to compensate for fibre loss and to extend the splitting factor of the system. In our system, the transmission fibre is used as the amplification medium and by using a combined forward and backward pumping scheme (see Figure 1) high signal gain is provided to both up-and-downstream signals. Moreover, an attractive feature of DRFA is its low noise figure and highly adaptive gain profile, by simple control of the pump powers, thereby allowing accommodation of changing traffic and/or increased number of splitting points.

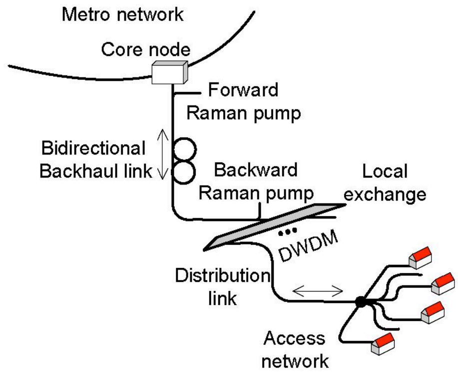

Figure 1. Extended reach access system with single fibre, bidirectional backhaul link and distributed Raman amplification.

Experimental setup

The experimental setup depicted in Figure 2 uses two Mach-Zehnder $LiNbO_3$ intensity modulators, MZI_1 and MZI_2, to generate the downstream and upstream optical channels, respectively. The electrical signals (a 2^{31}-1 pseudorandom bit sequence pattern) are derived from the data and data invert outputs of a pulse pattern generator (PPG). The optical carrier wavelength of the upstream channel is 1547.72 nm and 1550.12 nm for the downstream one. The backhaul link is composed of 80 km of TrueWave®RS optical fibre. The employed optical receiver uses no optical pre-amplification.

Firstly, we describe the signal path for the downstream channel. The optical circulator OC_1 allows us to combine the downstream signal with the forward Raman pump and direct the combined wavelengths into the backhaul fibre link. At the end of the fibre link, the downstream signal is directed by OC_2 into the receiver. The function of the optical bandpass filter $OBPF_1$ is to reject amplified spontaneous emission (ASE) noise from the DRFA and residual Raman forward pump power. Secondly,

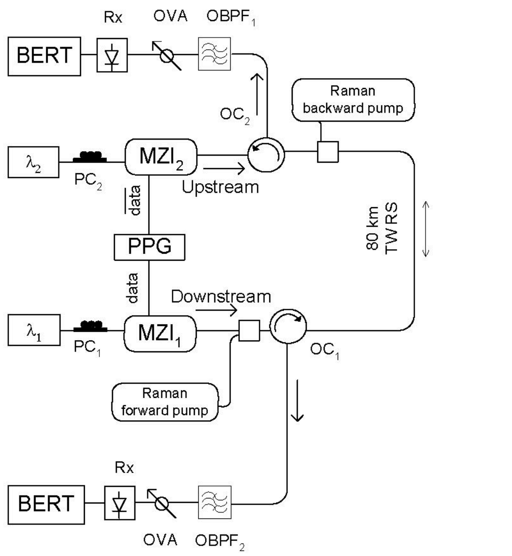

Figure 3. Experimental setup. TW RS: TrueWave reduced slope optical fibre. OVA: optical variable attenuator. OBPF: optical bandpass filter. OC: optical circulator. PPG: Pulse pattern generator. BERT: Bit-error rate test. MZI: Mach-Zehnder intensity modulator.

the upstream signal is launched into the fibre link by using OC_2 where it is combined with the backward Raman pump. At the other end of the fibre link, the upstream channel is directed to the receiver by OC_1. Here as well, ASE noise and residual backward pump power are rejected by $OBPF_1$.

The Raman pump signals used were at the following wavelengths: 1456.0 nm for the forward pump and 1437.2 nm and 1464.5 nm for the backward pumping scheme with corresponding power levels of 21.8 dBm, 22.0 dBm and 22.30 respectively. The pump wavelengths are combined with the up-and-downstream signals by using a coarse WDM (CWDM). The average input power of the downstream and upstream signal into the fibre links is measured to be -1.7 dBm and -3.0 dBm, respectively. The Raman pump on-off gain for is measured to be 13.0 dB for both downstream and upstream signals. The corresponding optical signal to noise ratio (OSNR) for the up-ad downstream signal, at the end of the fibre link were measured to be 43.0 and 41.0 dB, respectively, in a 0.1 nm noise bandwidth. No OSNR or on-off gain degradation was observed between uni-and bidirectional (simultaneous up-and-downstream) transmission. The measured eye diagrams for the up-and-downstream signal, back-to-back and at the end of the bidirectional backhaul link are presented in Figure 3. We can observe wide-open eye diagrams; however the effect of fibre dispersion is visible after transmission for both the up-and-downstream signals. However, the total dispersion of the used 80 km TrueWave®RS fibre link (400 ps/nm) is well under the value (960 ps/nm) for 1 dB eye closure penalty [5]. The results for the bit-error rate (BER) measurements are presented in Figure 4. The receiver sensitivity at a back-to-back configuration is -19.6 dBm, at a BER of 10^{-9}, for both the up-and-downstream signals. As it can be observed from Figure 4, bidirectional transmission results in a receiver sensitivity power penalty under 0.5 dB for the upstream channel and under 0.7 dB for the downstream channel.

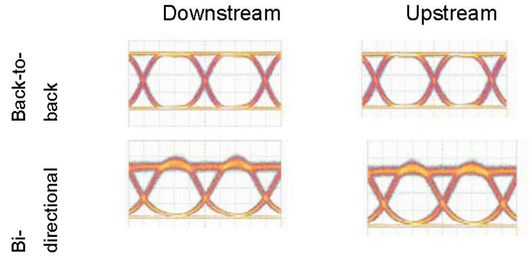

Figure 2. Measured eye-diagrams.

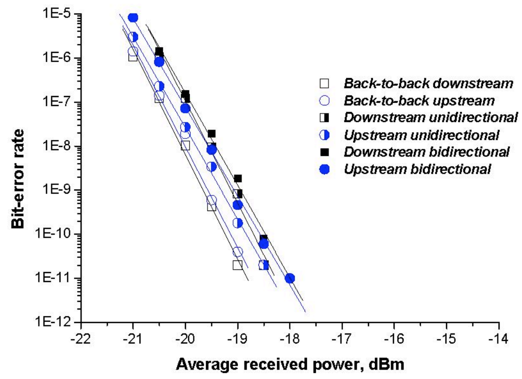

Figure 4. BER measurements.

It can also be noticed that there is no substantial observed difference in the BER performance between the uni–and bi-directional transmission cases for the system under study. We measured a power budget margin of 12.0 dB and 13.6 dB for the downstream and upstream channel, respectively, with regard to the receiver sensitivity at the end of the fibre link and the averaged optical power level measured after the OC_1 and OC_2 at the receiver side.

Conclusions

We have experimentally demonstrated an 80 km long, symmetric 10 Gb/s bidirectional long reach PON link supported by distributed Raman amplification only with low transmission power penalty. Our proposed single fibre backhaul link contributes to lowering the cost per unit of bandwidth in long reach access systems as it reduces the amount of network elements and needs no dispersion compensating techniques.

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