Bi-directional 120 km Long-Reach PON Link
Based on Distributed Raman Amplification

Rasmus Kjær, Idelfonso Tafur Monroy, Leif K. Oxenløwe and Palle Jeppesen
COM•DTU, DTU, Ørsteds Plads 345V, 2800 Kgs. Lyngby, Denmark
E-mail: rkJ@com.dtu.dk
Bera Palsdottir
OFS Fitel Denmark, Priorparken 680, 2605 Brøndby, Denmark

Abstract—We propose and demonstrate a bidirectional PON link with 120 km reach and symmetric up and down stream data rate of 10 Gbit/s. Lossless transmission was achieved with >40 dB of received OSNR.

I. INTRODUCTION

Long reach access networks have been proposed as a promising way to reduce the unit cost of bandwidth in fiber-to-the-premises (FTTP) solutions [1], [2]. Long-reach access is based on the idea of using a high-capacity, high-split passive optical network (PON), with a reach of ~ 100 km, to combine optical access and metro into a single system [3]. Systems with symmetric upstream (US) and downstream (DS) data rates of 10 Gbit/s, split factors of 1024 and link lengths up to 135 km have been reported [1], [3]. These demonstrations, however, make use of advanced schemes such as FEC and EDC [1] and separate fibers and amplifiers for the US and DS signals [1], [3]. We recently proposed a simple, bi-directional, 80 km PON link based on distributed Raman amplification (DRA) and non-zero dispersion-shifted fiber (NZDSF) [4]. This link design is advantageous since it combines the US and DS signals on a single fiber and features superior noise performance compared to terminal-based amplification, due to the distributed Raman gain. Furthermore, the low dispersion parameter of the NZDSF reduces the need for dispersion compensation.

In this paper, we demonstrate error-free, bidirectional transmission of 10 Gbit/s/channel across a 120 km PON link, with no observed penalty due to bi-directionality, with positive net gain for all channels and a received OSNR after transmission in excess of 40 dB. The high on-off gain and good noise performance is obtained using a combined forward and backward pumping scheme and could potentially enable high splitting factors. No dispersion compensation was used.

II. EXPERIMENTAL SETUP AND RESULTS

The proposed bidirectional long-reach PON link, along with the surrounding networks, is shown in Fig. 1. The PON link is connected to the metro core node and has a typical length of ~ 100 km. The link delivers signals to and from the local exchange, where the dense wavelength division multiplexing (DWDM) channels are further distributed to the splitting points at the access part of the network.

The experimental setup is shown in Fig. 2. Two Mach-Zehnder LiNbO₃ modulators (MOD) are used to generate the US and DS signals. The electrical signals (a 2³¹ − 1 PRBS pattern) are obtained from the data and inverted data outputs of a pulse pattern generator (PPG). The optical wavelength of the upstream channel is 1548.0 nm and 1550.4 nm for the downstream channel. The PON link is composed of 120 km TrueWave RS with a total passive loss of 24.6 dB and a total dispersion of 550 ps/nm at 1550 nm. The employed optical receiver uses no optical pre-amplification.

In the bi-directional case, both the US and DS channels are coupled into the PON link using two optical circulators placed at each end of the link. Before transmission, the signals are multiplexed with two co-propagating Raman pumps using a coarse WDM. In this architecture, the signals will see both co- and counter-propagating pumps during transmission. The US and DS signal power into the link (after the WDM) is -1.3 dBm and -2.3 dBm, respectively. The wavelengths of the upstream pumps are 1437 nm and 1465 nm with respective input powers of 165 mW and 180 mW. The wavelengths of the downstream pumps are 1427 nm and 1456 nm with respective input powers of 231 mW and 279 mW. At the end of the link, the circulator routes the signal to the receiver, where an optical bandpass filter (BPF) is used to reject the amplified spontaneous emission (ASE) and backscattered power from the counter-propagating channel.

In the bi-directional case, both the US and DS channels are
on and the net gain is measured to 2.9 dB and 2.2 dB, for
those channels, respectively. The corresponding on-off gain is
27.5 dB and 26.8 dB, which gives rise to a signal power at the
output of the link of 1.6 dBm (US) and -0.1 dBm (DS). The
received OSNR (noise spectral density measured in a 0.1 nm
resolution bandwidth) is measured before the BPF and is found
to be 40.9 dB and 41.9 dB for the US and DS, respectively.
With only a single channel turned on (uni-directional case),
the gain and OSNR of both channels increased by 0.2 dB,
indicating a very low level of gain saturation.

Simulations based on a numerical rate equation model,
which includes contributions from ASE noise, backscattering
and fiber data of the experimental fiber, was found to agree
well with the experimental gain values, with on-off gain values
within 1 dB of the experimental values. We also calculated
the level of multi-path-inference (MPI) noise due to double-
Rayleigh backscattering (DRB). This effect is known to be a
common limitation of high-gain Raman amplifiers. We found
the MPI contribution of the system to be less than -40 dB for
both the US and DS channel, meaning that MPI is not limiting
the performance and can be neglected at these pump powers.

Measurements of bit-error-rate (BER) as a function of
input power are shown in Fig. 3 for both channels. The
channels have been characterized in the case of back-to-back
(no transmission), after uni-directional transmission and after
bi-directional transmission. The sensitivity is defined as the
minimum power at which a BER of $10^{-9}$ can be obtained.
We find the back-to-back sensitivities to be -18.8 dBm and
-19.6 dBm, for the US and DS channel, respectively. After
uni-directional transmission, we find a sensitivity penalty of
0.8 dB (US) and 0.9 dB (DS) and for the bidirectional case,
the penalty is 0.7 dB (US) and 0.8 dB (DS), compared to
back-to-back. All in all, penalties of less than 1 dB are found
in all four cases and no performance degradation was found
when comparing bi- to uni-directional transmission.

To illustrate the link potential, a power budget for a PON
system with 1/8 splitting ratio can be estimated. By assuming
a loss of 6 dB in the local exchange DWDM, a split loss of
9 dB, a combined connector and splice loss of 1.5 dB and
up to 4 dB of loss due to transmission (10 – 20 km) in the
access network, the total loss add up to 20.5 dB. With the
current output power of ~1 dBm and receiver sensitivity of
-18 dBm, a modest increase in gain of 3-6 dB would provide
an acceptable power redundancy for practical use. The gain
increase could be obtained by a simple increase in the pump
powers or signal input power. The power budget shows a clear
potential for the DRA-based long-reach PON link, especially
for systems with low splitting factors and high capacity.

III. CONCLUSION
We have tested a simple design for a long-reach PON link,
based on a single bi-directional NZDSF fiber employing dis-
tributed Raman amplification. After 120 km of transmission,
without any use of dispersion compensation, we find received
OSNR values in excess of 40 dB, transmission penalties
limited to $\sim 0.8$ dB and no increased penalty due to the bi-
directional operation. To conclude, we find the bidirectional
long-reach PON link to be an excellent candidate for future
long-reach access systems.

REFERENCES
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