Budget Extension Schemes for Nx10 Gbit/s DPSK-based TDM/WDM PON

A. Emsia, Q. T. Le, T. von Lerber, D. Briggmann and F. Kueppers
Institute of Microwave Engineering and Photonics, TU Darmstadt, Merckstr. 25, Darmstadt, Germany

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Abstract: We present a new TDM/WDM PON scheme utilizing PSK (phase shift-keying) at 10 Gbit/s per λ-channel as the modulation format along the feeder line and an SOA (semiconductor optical amplifier) as the amplifying component at the remote node. One single DLI (Delay Line Interferometer) converts all λ-channels from PSK to OOK (on-off keying), the modulation format which is used along the access line and one single SOA are experimentally demonstrated to be sufficient providing a power budget increase of up to 46.8 dB.

1 INTRODUCTION

Fibre-to-the-Home (FTTH) or Building (FTTB) is an access network technology that delivers the highest possible speed of Internet connection by using optical fibre that runs directly to the home, building or office. Gigabit-capable Passive Optical Network (PON) systems, such as GPON standardized by ITU-T G.984 and G-EPON standardized by IEEE 802.3ah, are now being mass-deployed in various FTTH/B markets around the world. These systems use Time-division multiplexing (TDM) / Time-division Multiple Access (TDMA) to manage the connection of N users (up to 128) to one optical port, the connection between end users and Optical Line Terminal(OLT) (Willner et al., 2009) (Jia et al., 2010) (Davey et al., 2006). The follow-up PON solutions use 10 Gbit/s for downstream transmission known as XGPON (ITU-T G.987) and 10GE-PON (IEEE p802.3) based on the same TDM technology. With the continuous increase in bandwidth demand generated by consumer and business applications (HD TV, cloud computing, online gaming, video-conferencing, etc.), and with the requirements of high-speed mobile backhaul for Long Term Evolution (LTE) networks, the need for a new, higher capacity access architecture becomes clear. Wavelength-division-multiplexed passive optical network (WDM-PON), whose simple topology is shown in Figure 1, is an efficient choice for future fibre access networks, and one of the most likely to solve the challenges of next generation access network (NGAN) as it can provide a point-to-point connectivity to multiple remote locations sharing the major part of the fibre plan. This WDM-PON architecture provides the most scalable, cost effective, and future proof solution available to address the capacity, security, and distance capabilities that network operators require while leveraging the benefits of a passive infrastructure. All these factors combine to make WDM-PON poised to become the disruptive next-generation access solution. It will enable high speed access for business, mobile backhaul, and eventually FTTH, while also enabling operators to build converged networks and consolidate the access network.

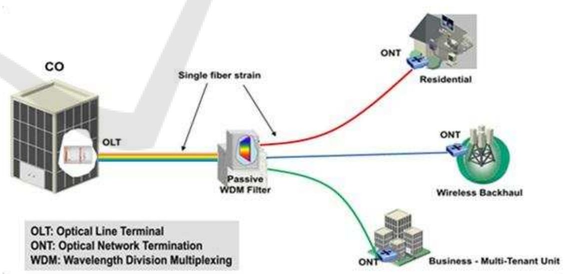

Figure 1: Wavelength-division-multiplexed passive optical network.

In this paper, we present a new TDM/WDM PON configuration based on Return to Zero(RZ) phase shift-keying signal (PSK) at 10 Gbit/s. The network extension by the use of a single semiconductor optical amplifier (SOA) for all channels is demonstrated.

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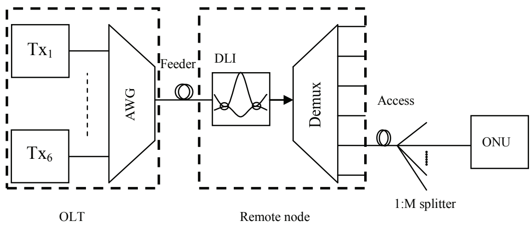

Figure 2: Downstream WDM PON architecture.

2 WDM PON ARCHITECTURE

The proposed architecture is shown in Figure 2. It is comprised of 5 elements: 1) Optical Line Terminal (OLT), 2) the feeder line, 3) the remote node, 4) splitters and the access line, and 5) Optical Network Unit (ONU). In this architecture, the PSK signal is considered for downstream transmission as it has many advantages compared to conventional OOK modulation format (for instance, better tolerance to fibre dispersion and non-linearities). The OLT consists of DPSK transmitters which offer the wavelengths from 1 to N for downstream each to its own TDM PON tree (splitters in the Figure 2 represent the PON trees). In upstream scenario, TDM technology used to transmit signals up to OLT. Each user has a dedicated time slot.

At the remote node, only one DLI is used regardless of number of channels.Namely, all six wavelengths are converted from DPSK to OOK at the same time, no need to demodulate the channels separately. The DWDM signals are then demultiplexed by an AWG demux and the wavelengths are sent to respective individual TDM PON trees. At the ONU, the receivers need no individual demodulators, because the modulation format transformation from the DPSK to OOK is performed simultaneously for all ONUs at the remote node. The proposed downstream PON is therefore compatible with commercial XGPON1 network terminals. Only DPSK downstream transmission at the OLT is needed, which could be performed by cost-efficient direct phase, or frequency modulated lasers (Vodhanel et al., 1990) (Maher et al., 2010). The budget extension by the use of a single SOA at the remote node is experimentally demonstrated and the possibility to use a saturated collision amplifier (SCA) (Tervonen et al., 2010) is discussed in the next sections.

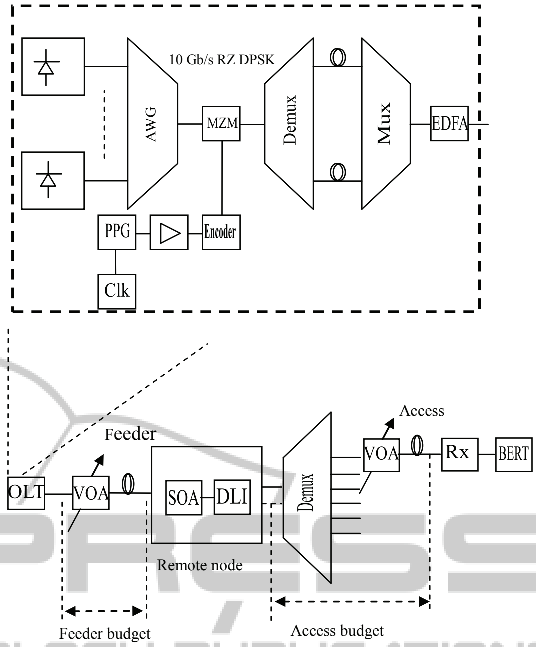

Figure 3: Measurement setup.

3 MEASUREMENTS

3.1 Experimental Setup

The measurement setup is shown in Figure 3 where six downstream channels of 10 Gbit/s PON are at 1537.388 nm,1542.93 nm ,1543.64 nm,1553.329 nm ,1554,101 nm ,and 1556.55 nm generated by DFB laser diodes. The channels are combined through AWG and modulated by Mach Zehnder Modulator. The modulator operates in push-pull mode and generates RZ-DPSK signals at 10 Gbit/s (PRBS of 2^{31}-1). In order to have uncorrelated data on each wavelength, the channels are separated, transmitted through different fibre lengths and again combined by a multiplexer. The AWGs have 100 GHz channel spacing and 50 GHz 3-dB bandwidth. The EDFA is used to compensate the loss of the multiplexers and the demultiplexer, each channel has 8 dBm power at the input of feeder variable optical attenuator. The line between OLT and the remote node is termed as feeder line and the one between remote node and ONU is the access line.

A DLI is employed to convert DPSK into OOK signal. The receiver is a p-i-n photodiode with sensitivity of -17 dBm at BER 10^{-9} and -22 dBm 10^{-3}.

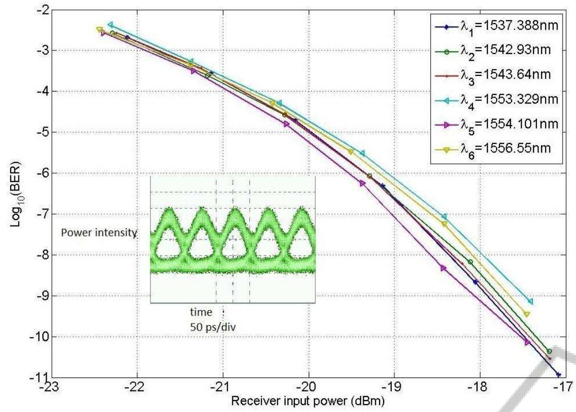

Figure 4: BER versus received power for the case without SOA.

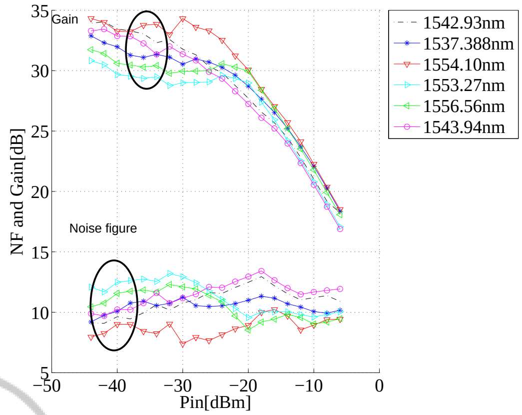

Figure 6: The noise figure and gain of SOA.

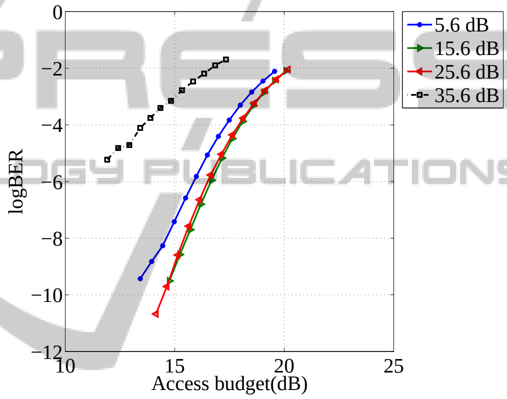

Figure 7: BER versus access budget for varying feeder budgets.

3.2 Experimental Results

The Figure 4 depicts the bit error ratio versus receiver input power for all six channels for the constructive output of the DLI as well as corresponding eye diagram of a channel. As mentioned above the sensitivity range of our receiver at the time of measurements was from -17 dBm to approximately -22 dBm. The measurements are done for back-to-back case in the absence of the SOA.

The Figure 5 demonstrates the spectrum of six channels with nearly the same power (the spectrum is acquired after DLI, refer to Figure 2). All six channels show almost the same performance.

The SOA is now considered in the setup as depicted in the Figure 3 to see how it will improve the power budget of the link. The bias current of SOA is set to 300 mA at the temperature of 17.2 ^{o}C. The Figure 6 displays the gain and noise figure of the SOA used in the experiment for vairous channels. The highest gain of 34.8 dB is achieved at 1554.10 nm with NF of 8.5 dB.

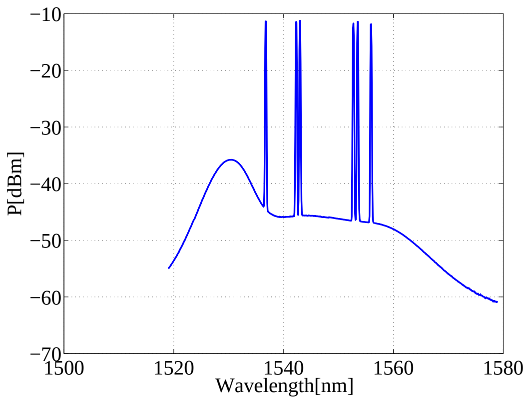

Figure 5: The spectrum of all channels, BWR 0.1nm.

The Figure 7 displays the bit error ratio curves over access budget for different values of optical feeder budget considering one channel (1543.64nm).As seen, for larger values of feeder budget, the bit error ratio decreases. This is due to domination of ASE noise produced by the SOA. On the other hand lower values of feeder budget show weaker performance, this may be a result of non-linearities caused by the SOA.

The Figure 8 illustrates BER map for 1543.64 nm.Considering use of forward Error Correction(FEC),the BER of 10^{-3} can be selected. In this case, at the feeder budget of 17.5 dB the access budget is 18.5 dB. Therefore, the total optical budget is 36 dB. An avalanche photodiode (APD) can be used to further increase the access budget of the system. In the absence of SOA, the maximum feeder budget can be 21 dB, however, SOA can result in higher feeder budget. In other words, the input signal to the feeder can be attenuated more than without SOA. For instance, in the Figure 8 at feeder budget of 30 dB we have access budget of 16.8 dB, this gives total optical

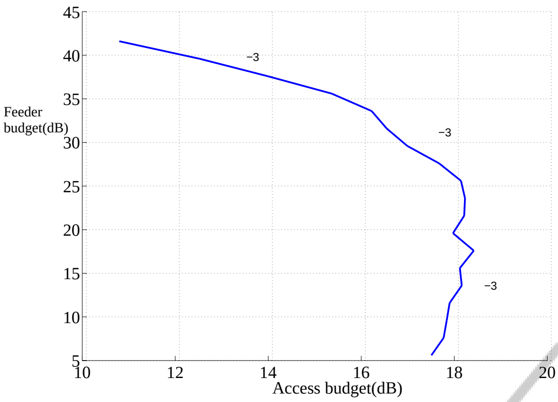

Figure 8: BER map of 6-wavelength setup.

budget of 46.8 dB.

4 SATURATED COLLISION AMPLIFIER

The SCA arrangement consists of a delay interferometer, a pair of circulators, and an SOA (see Figure 9). The delay interferometer demodulates the input DPSK signal into a pair of complementary OOK signals that are coupled into the circulators, which direct the opposite polarity signals through the SOA (Tervonen et al., 2010). The signals are amplified while they simultaneously traverse the SOA gain medium from the opposite directions, and finally the signals are coupled out via the circulators.

As discussed in (Tervonen et al., 2010), this arrangement permits saturated SOA operation, which results in the maximized output power, low ASE noise, and virtual absence of pattern effects. In other words, the common negatives of an SOA are effectively mitigated. We compared the performance when the SOA was used in the conventional linear regime with the SCA arrangement and found up to 10-dB power budget improvement from a single output arm. When the output doubling is taken in account, the power budget improvement over the linear operation SOA rises up to 13 dB. In collaboration with Orange-France Telecom Labs we show in (Le et al., 2011) that the SCA arrangement can even be used for amplification of multiple simultaneous wavelengths without a noticeable penalty. And the compatibility of the SCA for reach extension of a commercial single-wavelength XGPON1 system was experimentally demonstrated (Saliou et al., 2011).

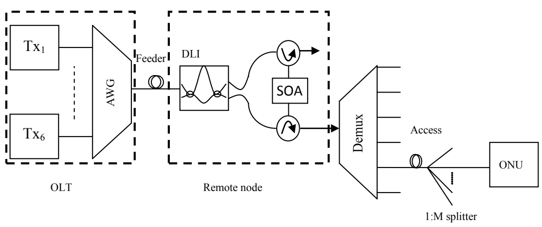

Figure 9: TDM/WDM using SCA.

5 CONCLUSIONS

In this paper, a power budget extension scheme has been shown. We demonstrated our scheme using a SOA and one DLI. Optical budget extension of 46.8 dB with in a 10 Gbit/s TDM/WDM PON was achieved. We showed that there is trade-off between higher and lower values of the feeder budget. The experiment performed for six-channel case, i.e., for total transmission of 60 Gbit/s.

6 FUTURE WORKS

The SCA power extension method has been explained in section 4. The SCA has not been investigated for 60 Gbit/s WDM/PON system. One of the future works will be to investigate the difference between the single SOA and the SCA setup. Additionally, the bit rate will be increased to see the performance of the proposed model. Furthermore, power equalization in burst mode transmission in upstream case is under investigation in the laboratory.

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