Dynamic Range in Hybrid DWDM/TDMA PON

Martin Bouda and Takao Naito

Fujitsu Laboratories of America, 2801 Telecom Parkway, Richardson, USA, martin.bouda@us.fujitsu.com

Abstract *We studied four-wave mixing in hybrid DWDM/TDMA PON operating in the 1.3µm band experimentally and show feasibility of 15dB dynamic range at 50GHz channel spacing with 28 channels without, and 7 channels with backhaul fibre.*

Introduction

Millions of subscribers are already connected today via PON systems such as GPON[1] and deployment of such systems will continue in the next few years, further increasing the base of existing PON equipment that will need to be upgraded in the future to continue meeting demand for bandwidth.

We have proposed several cost-effective ways to upgrade capacity of existing systems without having to replace user-side equipment[2]. For capacity upgrades in upstream direction, from subscriber to central office, we have proposed a novel approach based on a combination of WDM and TDMA, in which upstream transmitter wavelengths are allowed to drift and where the receiver is capable of scheduling multiple concurrent burst transmissions in closely-spaced channels, avoiding collisions[3].

However, the cost benefits of equipment re-use and cost savings on subscriber-side come at the cost of higher complexity of system design. In the proposed architecture, large numbers of closely-spaced wavelengths can result in significant non-linear effects in amplifiers and optical fibre, limiting the dynamic range of the upstream interface.

In this paper we report results from feasibility experiments aimed at quantifying the limitations due to four-wave mixing (FWM). In the next sections we present the architecture, the experimental setup and results, followed by a discussion and conclusions.

Architecture

The hybrid WDM/TDMA-PON architecture in Fig. 1 is based on the characteristics of practical PON systems being deployed today, operating in the 1.49µm window in downstream direction, and in burst mode around 1.31µm in upstream direction. In downstream direction, multiple wavelengths are easily introduced by adding wavelength-selecting filters in the distribution network or at the downstream end at the terminal marked ONT in the form of plug-in optical filters, and using wavelength stabilized transmitters.

In upstream direction, stabilising the wavelengths would require replacement of every one of the commonly used uncooled DFB lasers by more expensive devices. Using uncooled coarse WDM DFBs with spacing of about 20nm to allow the lasers to drift in wavelength within each band would limit the number of wavelengths to only a few, results in more ASE noise around the signal reaching the receiver, and would still require new deployment of multiple distinct laser 'colours' which is generally not desirable.

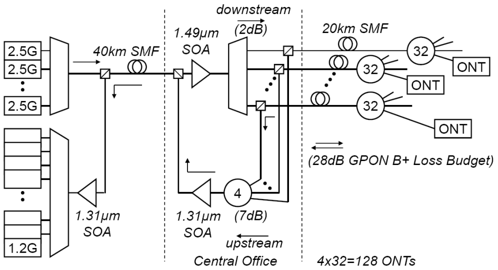

Fig. 1: Extended reach hybrid DWDM/TDMA-PON.

A novel alternative approach is taking advantage of the burst mode TDMA nature of upstream transmission in PON systems, and the fact that there will be a built-in and dynamically changing distribution of actual DFB wavelengths due to manufacturing tolerances and temperature dependency of the lasers. As long as the receiver can demultiplex densely spaced upstream signals and avoid collisions of too closely spaced transmitters by proper scheduling, existing transmitters with the same *nominal* wavelength can be re-used while the PON operates at a large number of concurrently active wavelengths, thereby increasing upstream capacity.

However, the upstream wavelength range around 1.31µm is not very suitable for WDM transmission due to the low or zero fibre dispersion, leading to strong FWM. Furthermore, if upstream wavelengths are closely spaced and in great numbers, FWM will be more significant and limit the dynamic range or the maximum difference between signal power from the most remote subscriber and that of a subscriber located closest to the central office. A value of 15dB is typical in standard PON systems, including variation in transmit power between transmitters.

The following experiments intend to estimate with off-the-shelf components how FWM impacts this dynamic range and the number of simultaneously operating upstream wavelengths.

Experiment

In the setup shown in Fig. 2, the outputs of three transmitters were combined, to create a spectrum emulating a large number of upstream transmitters. Two of the transmitters were standard GPON DFB transmitters, modulated with a PRBS31 pattern and the third was a Fabry-Perot laser, generating a grid of

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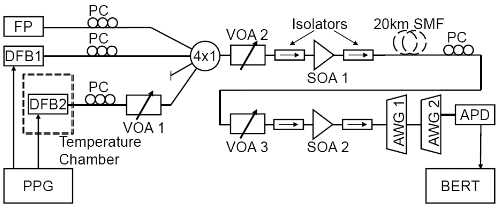

Fig. 2: The measurement setup with three 1.3µm lasers.

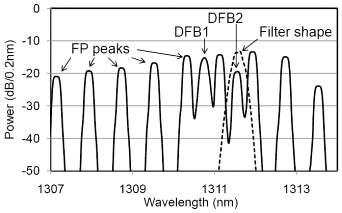

Fig. 3: The optical spectrum taken at 0.2nm resolution bandwidth and filter shape of two cascaded AWGs.

wavelengths to control the total SOA1 input power and to emulate the concurrent transmission of multiple wavelengths. The DFB transmitters were temperature-tuned to be 50GHz off the 100GHz spaced FP spectrum, as shown in Fig. 3. The polarizations of all sources were tuned to maximize four-wave mixing into the channel at which transmitter DFB2 operated to maximize the bit error rate (BER) in that channel. The power level of the FP peak between DFB1 and DFB2 was -14.3dBm and the total power of all signals was -6dBm, equivalent to 7 WDM channels at -14dBm. The power level of the signal from DFB2 and overall power were controlled using VOA1 and 2.

A booster semiconductor optical amplifier #1 (SOA1) amplified all signals to a total of 13dBm or more depending on the injection current. SOA1 operated in moderate to deep saturation. The relation between current and total output power is shown in Fig. 4. The output was passed through 20km of SMF and fed into an SOA pre-amplifier (SOA2), which compensated the 16dB loss in the cascade of two AWGs that were temperature tuned to realize a narrow filter pass band as shown in Fig. 3 to select the signal from DFB2. The signal was detected using an APD in a standard XFP module.

Fig. 4 shows the maximum difference in signal power of the signal from DFB2 relative to the FP peak between the signals from DFB1 and DFB2, as function of the power of the FP peak on the horizontal axis, to keep the bit error rate (BER) at 5E-4, well below the 1.3E-3 BER FEC limit. The plot includes minimum dynamic range requirements for 28dB and 35dB loss budgets for reference. The top curve corresponds to the case without any FWM. The curve below that was taken with DFB1 enabled, but still without any SMF inserted. The remaining curves with open markers correspond to cases with SMF included, at various fibre launch powers, which depend on the injection current of SOA1. In all cases the signal was attenuated by 10dB before entering SOA2 to be in the optimum range.

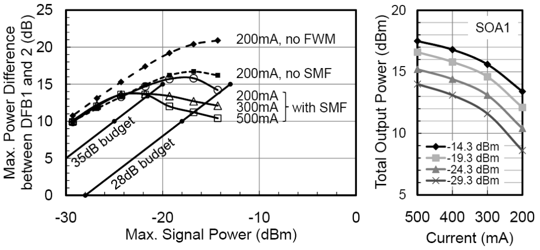

Fig. 4: Dynamic range versus signal power of strongest upstream signal (left) and SOA1 output power versus injection current and max. signal input power (right).

Discussion

The measurement results show that about 15dB dynamic range is feasible in a 50GHz spaced system provided there is no SMF between amplifier and receiver. The number of upstream wavelengths can be 7, or by combining 4 PONs and increasing the loss before the first amplifier by 6-7dB, it could be increased to about 28 at equal input power to SOA1. Changing the output power of SOA1 had no significant impact without fibre inserted.

The dynamic range is further reduced by FWM in fibre if SMF fibre is present, and as expected, strongly depends on the fibre launch power. The required launch power will depend on the required backhaul reach and the losses in the receiver. At lowest SOA1 current and with an assumed 35dB loss budget between subscriber and SOA1 input, a 15dB dynamic range was obtained with 7 upstream wavelengths. Increasing the number of wavelengths would require relaxing of the dynamic range required to 10dB to allow 28 concurrently operated wavelengths.

In a practical system, the total worst-case FWM into a channel could be higher than measured since multiple FWM components from other mixing signals will add. On the other hand, realizing maximum FWM efficiency requires close to perfect alignment of polarizations. Also, suitable scheduling of upstream transmission can further reduce the impact of FWM. Therefore we believe that the results are a good indication of feasibility of the proposed architecture.

Conclusions

In a standard reach PON with 50GHz channel spacing, upstream transmission was achieved with a dynamic range of 15dB, and with total signal power equivalent to 28 channels. In extended reach PONs using SMF backhaul fibre the number of wavelengths is limited to about 7 at 50GHz unless the dynamic range is relaxed to 10dB to allow the same number of 28 concurrent upstream wavelengths.

References

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