SOA or EDFA Amplifying 10Gbit/s OFDM Signals for Access Networks

F. Saliou, P. Chanclou, B. Charbonnier, T.N. Duong, N. Genay, A. Gharba, J. Le Masson, C. Milion, M. Ouzzif
Orange Labs, 2 av P. Marzin, 22307 Lannion, France, fabienne.saliou@orange-ftgroup.com

Abstract An OFDM transmission system is amplified through SOA or EDFA to provide an access network at 10Gbit/s with increased optical budgets. Bit-rate optimization and BER measurement characterize amplifier's behaviour with OFDM signals for access network.

Introduction

Next generation access networks discussed in FSAN and IEEE exposed two main objectives for the following years. On one hand the need to increase the overall bit rate, in order to provide more bandwidth to each costumer [1]; on the other hand an increased reach is also needed to improve the eligibility of PONs (Passive Optical Network), to provide FTTH to more customer cost-efficiently [2].

Recent research activities in access network have been focusing on Adaptively Modulated Optical Orthogonal Frequency Division Multiplexing (AMOOFDM) as a cost effective and upgradeable solution to increase PONs bit rates [3-4]. The main advantage of AMOOFDM is that it can transmit parallel data at low rates on each sub-carrier simultaneously. Therefore a frequency selective channel is transformed into a collection of flat channels. As a result, this modulation technique inherits robustness to fibre chromatic dispersion. In addition, with the high spectral efficiency, AMOOFDM has become extremely popular due to its low-cost implementation with conventional low-bandwidth components.

Furthermore, long reach PON studies point out several solutions to increase the optical budget of PONs. Among them, optical amplification based on SOA (Semi-Conductor Amplifier) or EDFA (Erbium Doped Fibre Amplifier) are promising technologies since they are low-cost transparent solutions (bewared of the optical noise funnelling) to obtain up to 50dB of total optical budget [5-6].

With a goal to increase both bit rate and reach, OFDM can be combined with optical amplification. Indeed, we evaluated SOA and EDFA capabilities to extend the optical budget, transmitting OFDM signals up to 10Gbit/s.

Experimental setup

Similar to our previous work [4], the electrical OFDM signal is generated through an AWG (Arbitrary Waveform Generator). At the transmitter, an incoming binary data sequence is divided into 255 parallel sub-carrier data streams. Each sub-carrier is then converted into complex values according to an M-QAM mapping. The M-QAM mapping is chosen according to the frequency response and noise of the transmission link at this particular frequency. This OFDM signal modulates a DFB (Distributed Feed Back) laser emitting at 2.5dBm at 1539.9nm with an electrical spectral bandwidth of 2,5GHz. Then, as shown on the experimental setup on Fig.1, the optical OFDM signal is transmitted through a link consisting of 10Km of SMF (Single Mode Fibre) and a VOA (Variable Optical Attenuator), standing for the optical budget. This first link, before amplification, will be define as the "Trunk 1" optical budget.

Then, the signal is amplified by a SOA or an EDFA. The SOA has a bandwidth of 50nm centred at 1560nm. Its saturation output power is 7dBm; NF (Noise Factor) is 8dB and gain is 21dB at an input power of –30dBm. EDFA's bandwidth is 35nm centred at 1548nm. Its saturation output power is 0dBm; NF is 4dB and gain is 40dB at an input power of –40dBm.

Next, the amplified signal is transmitted again through 10km of SMF and a VOA, defining the "Trunk 2" optical budget. None optical filter is used in this experiment. Finally, an APD (Avalanche Photo Diode) with an electrical spectral bandwidth of 2,5Ghz receives this optical signal which is transmitted to an A/D (Analog to Digital) converter for the OFDM demodulation process.

Results and discussion

With this experimental scheme, we evaluated the impact of introducing amplifiers in OFDM transmission. We measured the possible bitrates at a target BER (Bit Error Rate) of 10^{-4}, considering that by integrating a Forward Error Code (FEC), it will provide an error free transmission.

By varying the input power in the SOA or EDFA and at the APD receiver, we measured possible bitrates and the total optical budget. Represented on Fig.2

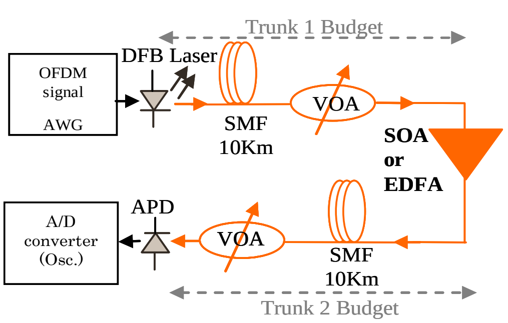


Fig. 1: Experimental Setup

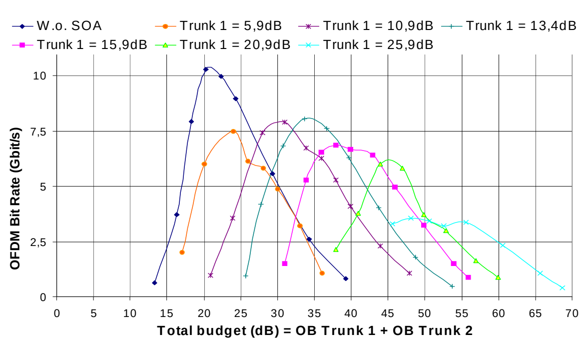


Fig. 2: OFDM bitrates optimization at a BER=$1,2.10^{-4}$ for total budget with SOA at different input powers

978-3-8007-3173-2

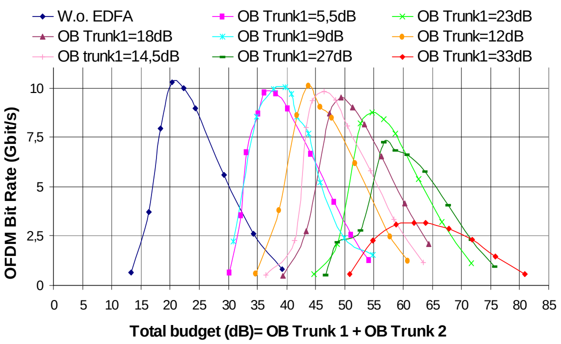
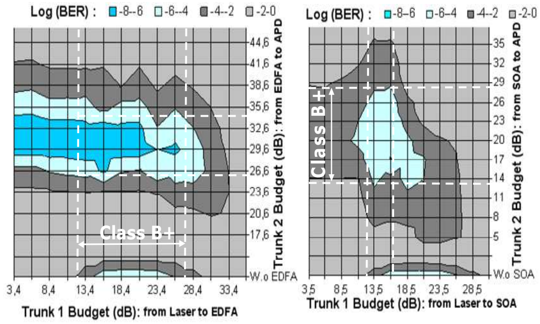


Fig. 3: OFDM bitrates optimization at a BER=1,2.10^{-4} for total budget with EDFA at different input powers

and Fig.3, respectively for the SOA and the EDFA, we obtained several curves where a BER of 1.2.10^{-4} is guaranteed. We could also present these results as a function of the received power at the APD or as a function of the optical budget of trunk 1 or 2. Observing these results, we can notice that without amplification we can reach a maximum bit rate of 10,3Gbit/s for an optical budget of 20dB (Pin_{APD} = -22.5dBm). This first curve on Fig.2, is representative of the behaviour of the APD receiver (sensitivity and overload). Then looking at the curves with SOA, we observed the same behaviour but the insertion of the SOA degrades the maximum bit rate to 8Gbit/s for a total budget of 33dB. Moreover, the bit rate decreases as the optical budget increase due to the gain limit and the ASE (Amplified Spontaneous Emission) noise of the amplifier which degrades the output OSNR (Optical Signal to Noise ratio). Also, below a Trunk 1 budget of 13.4dB, the bit rate decreases because of saturation of the SOA. On Fig.4, the EDFA shows better results: in terms of budget, because of its higher gain, saturation input power and lower NF; in terms of bit rate thanks to possible lower distortion and better linearity to high bit rates. A maximum bit rate of 10Gbit/s for a total budget of 44dB is obtained.

We also evaluated the interest of inserting an optical filter to reduce the impact of the ASE noise. Filtering with a CWDM (20nm), a 5nm width filter, or an AWG (0.2nm) did not improve the results. The gain obtained by filtering the ASE noise was never enough to cover the insertion losses of the filters.

Thus, expecting a possible application for access network there is a trade-off to make between bit rate and total budget. We therefore evaluated the possible budget extension as a function of bit rates and input power in the amplifiers, measuring the BER at the APD receiver. We focused our study performing measurements at several bit rates: 2.5Gbit/s, 5Gbit/s and 7.5Gbit/s. E.g. BER cartographies at 5Gbit/s, as a function of optical budget before and after EDFA and SOA are presented respectively on Fig.4 (a) and (b). These graphs were drawn by measuring the BER while



(a) (b)

Fig. 4: Optical Budget cartography: BER at 5Gbit/s with an EDFA (a) and SOA (b)

varying both optical budgets on Trunk 1 and on Trunk2 with a 2.5dB step. EDFA's cartography shows that considering a class B+ budget (13 to 28dB) before amplification, we can extend the budget on Trunk 2 from 26dB to 34dB, providing a total budget up to 62dB at 5Gbit/s. Also, the SOA's cartography shows that a Class B+ budget is obtained after amplification with an extended budget on Trunk 1 from 13 to 16dB. These results show that at 5Gbit/s an EDFA is a good candidate to amplify upstream OFDM signal, whereas a SOA would be more suitable for a downstream transmission.

Conclusions

We propose here to implement optical amplification with EDFA and SOA to extend the optical budget of access networks based on OFDM transmission. Bit rate optimization and BER measurements provides optical budget extension results, showing the behavior of such amplifier with OFDM signals.

In Tab.1, we summarized best performances and compared NRZ and OFDM with in-line amplification at 2,5 and 10Gbit/s. With similar power range at Tx and Rx, main conclusion is that optical amplifiers with OFDM transmission can provide a significant optical budget (45dB) at high bit rates (>5Gbit/s) with lower cost components at 2,5GHz, compared to 10GHz NRZ technologies,

Maximum Optical Budget (dB)		Electrical BW	No amplifier	SOA	EDFA
Bit rate: 2,5Gbit/s	**NRZ**	2,5GHz	35dB [1]	45dB [2] 50dB [5]	60dB
	OFDM	2,5GHz	34dB	60dB	71dB
Bit rate : 10Gbit/s	**NRZ**	10Ghz	30dB [2]	45dB [6]	55dB
	OFDM	2,5GHz	20dB	35dB (8Gbit/s)	45dB

Tab.1: Total Optical Budget performances comparison with NRZ or OFDM signals and with/w.o. SOA or EDFA

References

1 IEEE Standard, 802.3 (2008)
2 ITU-T recommendations, G984.6, (2008)
3 D. Qian et al, OFC'09, NME6 (2009)
4 T.N. Duong et al, OFC'09, NmE1 (2009)
5 R. Bonk et al., OFC'09, OwQ1 (2009)
6 Z. Belfqih et al., ECOC'08, Th2F4 (2008)