Optical Beat Interference in Burst Mode Upstream Links of the Higher Speed-PON: Situation, Penalties and Solution

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Abstract We perform a 25Gb/s NRZ-OOK burst mode transmission. A beating between two optical sources is detected on a DC-30GHz photodiode and a penalty due to OBI on the BER as high as 2.8dB is experimentally observed. Solutions to reduce the impact of OBI are proposed.

Introduction

The bandwidth hungry applications push the telecom industry to rethink all network segments, including the optical access network. Bitrates up to 50Gb/s in Intensity Modulation/Direct Detection (IM/DD) in Non-Return to Zero (NRZ) modulation format require higher bandwidth (BW) components than the previous Passive Optical Network (PON) generations. Increasing the component's BW in point-to-multipoint system is at risk. One of them is the Optical Beat Interference (OBI)[1-7], an impairment occurring when the wavelength difference of several light sources is small enough to pass within the receiver BW. In this paper, we explore the effects of the resulting OBI on the quality of the link, in the context of upstream next generation PON.

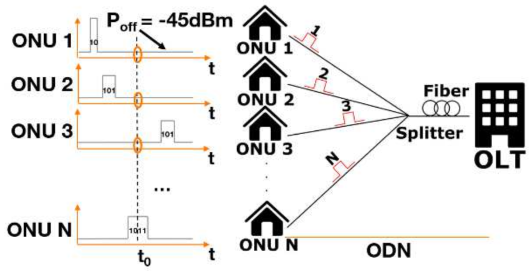

Fig. 1: TDM transmission over point to multipoint topology

Higher Speed PON (HS-PON)[8] is the next generation International Telecommunication Union (ITU) of PON standard. While it is still under work, the upstream requirements are between three options: 12.5Gb/s, 25Gb/s and 50Gb/s. In PONs, upstream links use Time Division Multiple Access (TDMA) with the help of burst mode transmissions on a point to multipoint topology (Fig. 1). Each ONU (Optical Network Unit) of the Optical Distribution Network (ODN) has an emitting time window managed by the Optical Line Termination (OLT). But, to permit the ONU to quickly (<10ns) enable and disable, the lasers are allowed to keep a maximum Off-level power (P_{Off}) of -45dBm between two bursts. Since these requirements for HS-PON is not currently published, this value is reported from the 10 Gigabit-capable symmetric PON (XGS-PON) requirements[9]. At t_0, during the detection of the burst of ONU number "N", the photodiode at the OLT side detects the wanted signal and the P_{Off} of all "N-1" others ONUs of the ODN. The reception of these N-1 signals coming from remaining Off-levels of ONUs induces a beating between wanted and unwanted signals. If the bandwidth of the photodetector is higher than the frequency difference between the signal of disabled ONUs and the signal of the emitting ONU, this beating will be detected and might degrade the quality of the transmission.

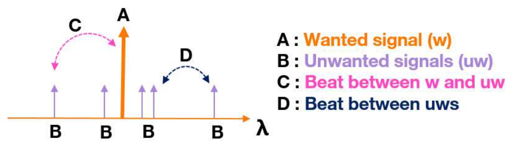

Fig. 2: Signals detected on the photodetector

On Fig. 2, the wanted (w) signal is represented by the arrow A, the other arrows are the unwanted (uw) signals coming from disabled ONUs (B) which all emit at slightly different wavelengths. In a burst mode transmission, we want to decode the wanted signal (A) of the current burst detected, but at the same time, we also detect unwanted signals (B). If the bandwidth of the photodiode is high enough, the beat between wanted and unwanted signal (C) but also the beat between the unwanted signals (D) are detected. The latter (D) is neglected, being less powerful than C. In the following paragraph, we propose a brief mathematical modelization of the phenomenon. We assume that the worst case

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scenario, when all unwanted signals wavelengths are close enough to the wanted signal to impact the transmission. For the sake of simplicity, we assume that they have the same wavelength λ and the same optical power P_{uw}. Eq (1) represents the power received by the photodetector at instant t. P_w represents the power of the wanted signal and P_{uw} the power of the unwanted signals. The two first terms, P_w and $(N\text{-}1).\,P_{uw}$, are the direct detection terms. The third term is the beating between wanted and unwanted signal. The product $2.\pi.t.(c.\Delta\lambda/\lambda^2)$ is the function of the detuning $\Delta\lambda$ in terms of signal wavelength λ. $\Delta\varphi$ is the phase mismatch between wanted and unwanted signals ($0\le\Delta\varphi\le2\pi$). The polarization matching terms are noted ρ ($0\le\rho\le1$). Also, we propose to introduce the parameter γ as the wavelength proximity probability of the different signal (w and uw). γ reflects the probability that an unwanted (uw) signal's wavelength is close enough to the wanted (w) signal's wavelength to create an OBI (i.e. $-BW<\Delta\lambda<BW$), according to the wavelengths standard deviation of the emitters and the photodiode BW. This standard deviation depends on the technology and fabrication process and can be as low as 0.2 nm[10],[11]. For this work we consider a Normal distribution with a standard deviation of 0.3 nm. Then, the corresponding γ probability can be as high as 0.41 for a photodetector BW of 30GHz.

$$I(t) \propto P_w + (N-1).P_{uw} + (N-1).2.\rho.\gamma.\sqrt{P_w.P_{uw}}.\cos(2.\pi.t.c.\Delta\lambda/\lambda^2 + \Delta\varphi) \quad (1)$$

In the next section, we propose to experimentally evaluate the impact of OBI. In order to simplify the experimental setup, we use only two sources, one to transmit data and the other one to emulate all disabled ONUs with a continuous wave (CW) emitter. In this case, Eq 1 simplifies in the following form.

$$I(t) \propto P_w + P_{cw} + 2.\rho.\gamma.\sqrt{P_w.P_{cw}}.\cos(2.\pi.t.c.\Delta\lambda/\lambda^2 + \Delta\varphi) \quad (2)$$

Where P_{cw} is the power of the CW source. We deduce from differencing (Eq 1) and (Eq 2) that $P_{cw} = \gamma^2.(N\text{-}1)^2.P_{uw}$. Then for emulating N disabled ONUs with only one CW source, we multiply the optical power by $(N\text{-}1)^2$ instead of N. Different splitting/combining ratios can be used on an ODN. By considering a γ probability of 0.41 and a 64:1 and 128:1 combining ratios, we obtain respectively a continuous power of P_{cw}=-16.75dBm and P_{cw}=-10.66dBm to emulate 63 and 127 disabled ONUs. We have to add the ODN propagation and splitting losses which are equal to at least 14dB, according to the N1 optical budgets class. Finally, to emulate 63 and 127 disabled ONUs, the equivalent continuous power is P_{cw}= -30.75dBm and P_{cw}= -24.66dBm, respectively.

Experimental setup

We experimentally assess the impact of OBI on a 25Gb/s NRZ-OOK (Non-Return to Zero – On-Off Keying) burst mode transmission. The experimental setup is similar to the one used in [12].

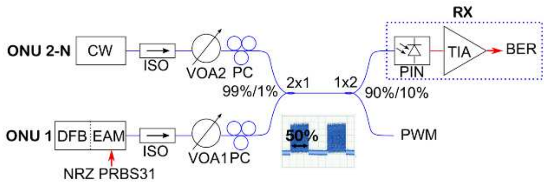

Fig. 3: Experimental setup

Two optical sources are used, the one labelled ONU 1 on Fig. 3, is a DFB-EAM (Distributed FeedBack laser and Electro-Absorption Modulator) which operates at a wavelength of 1310nm with an extinction ratio of 8dB. The EAM is modulated with a Non Return to Zero Pseudo Random Bit Sequence of length 2^{31}-1 bits (NRZ PRBS31) in burst mode with 50% duty cycle generate with a Pulse Pattern Generator (PPG). The chip is associated with an optical isolator (ISO) to avoid optical back reflections. To assess Bit Error Rate (BER) measurement, a Variable Optical Attenuator (VOA 1) is used. A Polarization Controller (PC) is inserted before a 2x1 coupler to control the polarization state of the signal. On the other branch of the coupler, a continuous optical source identified as ONU2-N aims to emulate the cumulative optical power of the disabled ONUs on the ODN. VOA 2 is inserted between the CW and a PC in order to control the optical power. Then, the signals coming from ONU 1 and ONU2-N are mixed in the 2x1 optical coupler mentioned before. The signal is detected with a photodiode PIN DC-30GHz on the other branch of the coupler. Finally, the amplitude of the electrical signal is amplified by a TransImpedance Amplifier (TIA) before the BER detector.

Experimental results and discussions

On Fig. 5, we present the BER measurement versus the received optical power for different wavelength detunings $\Delta\lambda$ with a 0.05nm step (corresponding to 8.7GHz step in O-band). We observe a penalty of about 1.8dB at BER=10^{-2}, between the worst case when $\Delta\lambda$=*0nm* (grey diamond curve) and the reference (green dash curve). $\Delta\lambda$=0nm corresponds to the case where the impact of OBI is maximum.

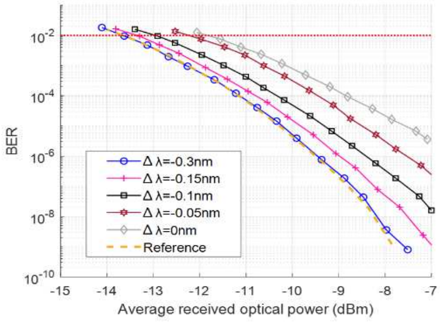

Fig. 5: BER versus average received optical power for different continuous signal wavelengths compare to the wavelength that maximise the effect of OBI ($\Delta\lambda$=0nm).

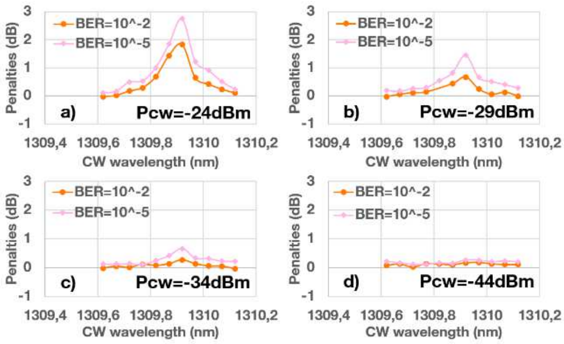

Fig. 6: Penalties versus the wavelength of the continuous signal for different optical power of the continuous signal

Fig. 6 show the OBI induced penalties versus the wavelength of the CW signal for different P_{cw} that emulate the P_{Off} of the disabled ONUs on the ODN. Those penalties at BER=10^{-2} and 10^{-5}, are extracted from measurement like those of Fig. 5, in comparing the performance for a given BER. On Fig. 6.a), the measurements show up to 2.8dB penalty at a BER of 10^{-5} and 1.8dB at BER=10^{-2} for a continuous power of -24dBm which corresponds to a P_{off} of -38.5dBm per ONU in a 64:1 topology. With the decrease of the continuous power, a reduction of the penalties due to the beating is observed (Fig 6.b) and c)) until the disappearance of the effect of the OBI on the BER at a continuous power of -44dBm. This power correspond to a P_{off} of -58dBm per ONU on a 64:1 topology (Fig.6 d)). Penalties are measured in a range of ~78GHz (44.8nm) with our DC-30 GHz photodetector. This corresponds to twice the bandwidth of the detector, since the penalty can appear when the unwanted wavelength is lower but also upper than the wanted signal's wavelength. In the same way, from BER curves at different wavelengths and CW powers, we measure the penalties on the BER at the same two BER values mentioned previously. These results are plotted for four wavelengths of the continuous signal on Fig 7. The penalties decrease with the increasing of the $\Delta\lambda$ compared to the $\Delta\lambda$ where the OBI effect on the BER is the highest. As we discussed before, for a splitting ratio of 64:1 and 128:1, we have a P_{Off} of respectively -30.75dBm and -24.66dBm. In the case where OBI effect is the greatest ($\Delta\lambda$=0nm), the penalty is 0.5dB for 64:1 at BER=10^{-2} and a penalty of 1.8dB for 128:1 at BER=10^{-2}. At a BER of 10^{-5}, these penalties can reach 1.4dB and 2.8dB respectively.

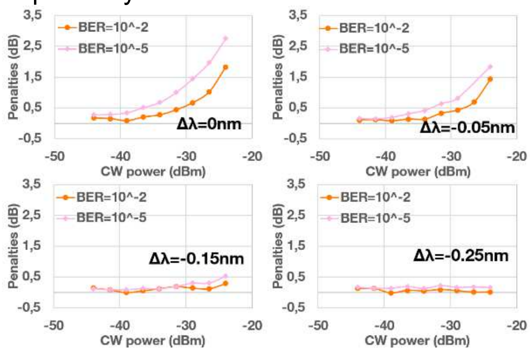

Fig. 7: Penalties versus the continuous signal power at different BER value

Conclusions

We experimentally investigate the impact of Optical Beat Interference on a 25Gb/s burst mode transmission for HS-PON. The OBI is a phenomenon which importance will increase as the receiver bandwidth does and while the allocated wavelength range remains the same (±10nm in both GPON and HS-PON). OBI penalties up to 2.8dB were observed. If we consider the requirements of the ITU-T about XGS-PON, we have observed maximum penalty of 1.8dB at BER=10^{-2} on a 128:1 topology. The effect of OBI is visible on a 78GHz range of ONU wavelength deviation, more than twice the bandwidth of the photodetector. This range correspond to a detuning of ±22.4nm between the wanted and unwanted signals. A potential degradation of the BER can be compensated by increasing the optical budget of the link. Another solution is to tighten the constraints on the output power of the unused emitters between two bursts. Finally, some solution utilizing MultiMode Fiber, Mode Coupling Receiver or injection locking[4-7] was also explored to reduce or suppress OBI.

Acknowledgements

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