OPTIMIZATION OF OPTICAL AMPLIFIER SATURATION POWER IN NGPON2 USING 2048 WAY SPLITTER

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ABSTRACT

This article represents design of Next Generation stage-2 Passive Optical Network (NG-PON) for a reach of 100km and over 2048 split using a hybrid time and wavelength division multiplexing (TWDM) for the data rate of 40Gbps. The down stream signal uses L band and upstream signal uses C band with the wavelength plan of ITU-T G.989. The network provides cost effective solution by directly connecting the increasing numbers of customers to the core network by use of 2048 way split. The splitter loss and the ASE noise is optimized by EDFA amplifiers to extend the long reach. An in-depth analysis is performed using an analytical model of NGPON with non- dispersion shifter fiber.

Index Terms—Next Generation Passive Optical Network (NGPON), Optical Network Units (ONU), Pseudo-Random Bit Sequence (PRBS), Electro Absorption Modulator (EAM), Optical Network Unit (ONU)

INTRODUCTION

In the recent few decades there is a tremendous increase in internet access such as e-mail, e-commerce, e-governance e-business etc. which requires a huge bandwidth and high data rate for longer distance. The increase in demand of bandwidth is met by using fiber optic cable which supports huge bandwidth along with high speed. In the evolution of fiber optic network, new generation network exist starting from SONET, PON and currently NGPON. Many network supports different types of multiple accessing technique such as TDM, WDM and now trend discuss about TWDM technique.

This technique supports tremendous increase in bit rate and huge bandwidth for long haul applications. The networks can be combine through a extended backhaul fiber for 100 km length. PON model consists of a Optical Line Terminal (OLT), distributed fiber, optical splitter and Optical Network Unit (ONU). A passive optical splitter is used to connect each customer to the main fiber. ITU standardized PONs have a maximum of 20 km in length with 16, 32, or 64-way splits for Ethernet-PON (EPON), broadband-PON (BPON), or Gigabit-PON (GPON), respectively.

Cost effective measurements is achieved. Now a days Next Generation Passive Optical network (NGP ON) is a blooming technology to offer a much higher bandwidth. A hybrid Time and Wavelength Division Multiplexing (TWDM) architecture is a promising candidate for NGPON and was proposed as a most cost-effective solution for long-reach optical access network. Demonstration of TDM-PON using 64-split for 42-km, having 40 Gbps using optical duobinary modulation, 31 dB of power budget is obtained [1].

The article discusses about types of splitters arrangement in the DSN and the requirement of total cable length for 2048-way-split in Long-Reach Passive Optical Network (LR-PON) [2]. This paper discusses about the spectral efficiency based on 64 quadrature amplitude modulation (QAM) and the scalability issues of existing PON [3]. This research paper contributes to a new proposed system of frequency interleaved direct detection to operate effectively over 100 km of single mode fiber with a 2048-way split and a receiver bandwidth of 25 GHz [4].

A 10Gbit/s error free transmission over a maximum of 80km of standard fibre including 20km PON distribution and 60km backhaul section [5]. The article explains DWDM operation up to 2560 users using a standard fiber for 120 km with different backhaul wavelength [6]. Here they discussed about PtMP PONs architecture to reduce cost instead of having a PtP architecture [7]. For a potentially user of 1280 with a distance of 120 km a PON designed for wavelength converting which uses multiple ONUs of similar specification to GPON, with 38.8 Mbit/s per user [8].

The feasibility of long-reach optical-access networks for 2048way split was designed for a 100-km with a bit rate of 10 Gbits for upstream and 40-Gb/s for downstream asymmetrical network [9]. High-speed, high-split-ratio in long-reach PONs were considered using expensive dense wavelength division multiplexing (DWDM) technologies in combination with TDM [10]. Higher bandwidth was achieved using Long reach PON (LR-PON) architecture. Cost effecttive broadband service delivered by the LR-PON [11].

An analytical model which has 2048-way-split and 10 Gbps data rate over the distance of 100 km having the details about the optical amplification, optical power margins, fiber loss coefficient, and optical bandwidth [12]. The maximum capacity PON currently available is given by ITU-T Recommendation G.984.1 ‘Gigabit-Capable Passive Optical Networks (GPON) [13]. The details about the Forward Error Correction and its precise measurement performance is being analysed [14]. Bayvel and Killey has designed WDM transmission network and explained the effects of nonlinearity [15] NGPON2 is used for multiple applications such as for multicast and unicast where RSOA is used for downstream wavelength modulation to obtain upstream wavelength [16].

II DESIGN METHODOLOGY

We designed a 40 Gbps NGPON2 network and examined the key parameters such as Bit Error Rate (BER), Q factor, fiber distance, optical filter bandwidth, frequency chirping parameter (α_c), noise figure, optical amplifier saturation power, ASE penalty and data rate in both downstream and upstream transmission paths using software design and modelling. Network accommodates a total of 2048 users designed using TWDM PON architecture.

A. Upstream Architecture for NGPON2

The upstream architecture can be mainly divided into four sections. Distribution Section, Local Exchange, Back Haul Section, Core Exchange as shown in fig1.

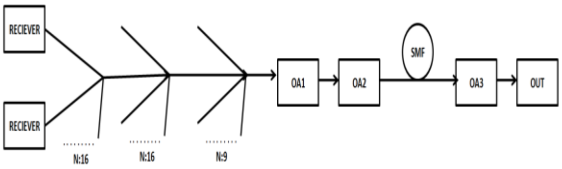

Fig 1: Upstream Architecture for NGPON2

Distribution Section is consisting of 2048 Optical Network Units (ONU), power splitters/combiners and distributed fiber length of 10 km. A CW laser with a frequency of 193.1 THz is used. Pseudo-Random Bit Sequence (PRBS) generator is used in each transmitter to model random data generated and modulated on the optical pulse. Very high speed Electro Absorption Modulator (EAM) is operated at 1 GHz.

In Distribution Section 2048way splitter used for 2048 Optical Network Units (ONU). i.e. cascading of two N: 16 and one N: 8. Power splitters with losses of 14.5 dB and 9 dB is used respectively [5]. Distribution fiber of 10 km is used with the power splitters. A fiber loss coefficient of 0.30dB/km is assumed. So, the fiber loss will be 3 dB in the distribution section. Additional Losses of 1.5 dB is used for 2048 splitter arrangement. This results in a total distribution section loss of 43 dB. To introduce these flexibility losses in the analytical model we will be using Optical Attenuators with the same losses.

The Local Exchange site is next to Distribution Section. It consists of two optical amplifiers with gain 25 dB. The optical signal generated will face a large attenuation of 40.3 dB in the Distribution Section as we discussed in the previous section. Optical Amplifiers are utilized to increasing optical power budgets. To have best system performance a single amplifier is not sufficient as the input signal is extremely small. The maximum output power is -15 dBm, with amplifier gain of 25 dB. A 90km feeder fiber has an attenuation of 34 dB. Signal at the receiver is −49 dBm, is below −20 dBm (BER = 10^{-10}).

The third Back Haul Section which consists of a 90km fiber with fiber loss coefficient 0.35dB/km. The attenuation loss in Back Haul Section will be 34 dB including 90 km fiber loss i.e. 31.5 dB and flexibility losses (local exchange out loss – 1 dB and Core exchange loss – 1.5 dB). Fourth section consists of an optical amplifier, a receiver filter and an Optical Line Terminal (OLT). Optical Amplifier increases the sensitivity of the receiver which forms an optically pre-amplified receiver.

B. Downstream Architecture for NGPON2

The downstream architecture is divided into four main sections Core Exchange, Back Haul Section, Local Exchange, Distribution Section as shown in fig2.

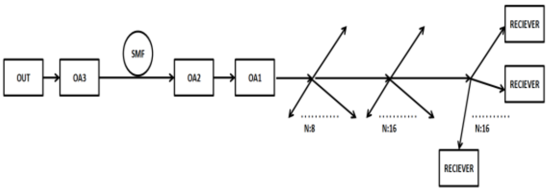

Fig 2: Downstream Architecture for NGPON2

NGPON2 SPECIFICATIONS

Table1. NGPON2 Specifications

Components	***Type***	***Value***
Optical Transmitter	Bit Rate	10 Gbps
	Wavelength	1310-1490 nm
	Extinction Ratio	10 dB
Optical Attenuator	CPE Loss	0.5 dB
	LE In Loss	1 dB
	LE Out Loss	1 dB
	CE Loss	1.5 dB
Fiber	Distribution Section	10 Km
	Back Haul Section	90 Km
	Fiber Loss Coefficient	0.35 dB/Km
Wdm Mux	Loss N:16	14 dB
	Loss N:4	7.3 dB
Optical Amplifier	Gain	25 dB
	Noise Figure	5-6 dB
Receiver	Sensitivity (@10^{-10}	-20 dBm
	Receiver Electrical Bandwidth	7.5 GHz

The first section of the downstream architecture has Optical Line Terminal (OLT) as a transmitter and followed by an Optical Amplifier (OA1). To achieve a large OSNR in the downstream path, which enables low BER, amplifier is kept after the transmitter with no increment in cost per user. The next Back Haul Section of 90 km fiber with fiber loss coefficient 0.35dB/km. The attenuation loss is 34 dB including 90 km fiber loss i.e. 31.5 dB and flexibility losses (local exchange out loss – 1 dB and Core exchange loss – 1.5 dB). The Local Exchange site next consists of two optical amplifiers with gain 25 dB. which has faced 34 dB attenuation in Back Haul Section and boost the optical signal to overcome the 40.3 dB attenuation loss which will be faced by the signal in Distribution Section.

Distribution Section is consisting of 2048 Optical Network Units (ONU) as receivers, power splitters/ combiners and Distribution section fiber of 10 km length. The Optical Network Units (ONU) as receivers are consists of a PIN or APD Photo detectors are used. The parameters used for simulation is given in table1.

III. SIMULATION RESULTS AND DISCUSSIONS

The NGPON2 is designed and simulated for 2048 users both in upward and downward direction. The performance of the network is tabulated in table 2.

Table2 Comparison of UP and DOWN stream parameters

ANALYSIS	UPSTREAM	DOWNSTREAM
MAX. Q Factor	16.0878	16.0465
MIN. BER	$5.68e^{-10}$	$7.3916e^{-10}$
EYE HEIGHT	$1.6528e^{-07}$	$1.641e^{-05}$
THRESHOLD	$1.547e^{-07}$	$1.790e^{-05}$

DFCF Performance when α_C is 0 and -0.7

The dispersion in LOAN is compensation by using EAM, and the results are summarized in table3 and the same is displayed in fig 3. It shows that for αc=-0.7, it gives less BER.

Table 3. DFCF Performance When A_c Is 0 And -0.7

Transmitter Power [dBm]	BER when α_c=0	BER when α_c=-0.7
0	$0.25*10^{-1}$	$0.1*10^{-1}$
1	$0.25*10^{-1}$	$0.56*10^{-1}$
2	$0.25*10^{-1}$	$0.32*10^{-1}$
3	$0.25*10^{-1}$	$1.00*10^{-3}$
4	$0.25*10^{-1}$	$1.58*10^{-4}$
5	$0.158*10^{-1}$	$6.30*10^{-5}$
6	$0.151*10^{-1}$	$6.30*10^{-5}$
7	$0.141*10^{-1}$	$1.00*10^{-6}$
8	$0.126*10^{-1}$	$1.00*10^{-7}$
9	$0.112*10^{-1}$	$1.00*10^{-8}$
10	$0.1*10^{-1}$	$1.00*10^{-9}$

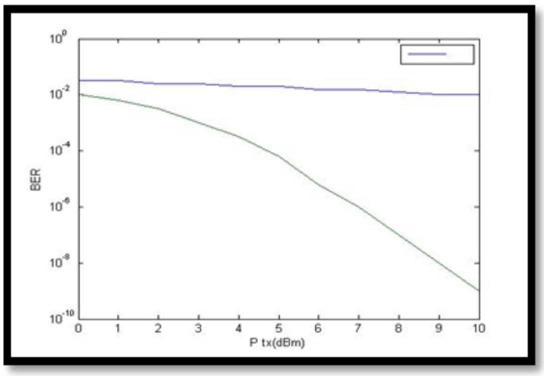

Fig 3: Upstream Performance When A_c Is 0 And -0.7

ASE Penalty Analysis:

Table 4: Q Penalty by OA1, OA2, and OA3

Noise Figure [dB]	Q penalty due to OA1	Q penalty due to OA2	Q penalty due to OA3
0	0	0	0
1	0.8	0	0
2	1.6	0	0
3	2.2	0.1	0
4	2.9	0.1	0
5	3.8	0.2	0
6	4.6	0.2	0
7	5.4	0.2	0
8	6.4	0.3	0.1
9	7.2	0.35	0.1
10	8.2	0.4	0.1

Table 4 shows the ASE penalty analysis for various position of optical amplifiers. The Q factor is analyzed for various Noise figure and summarized and the same is shown in figure4.

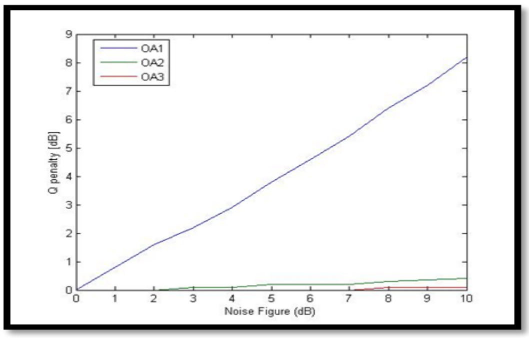

Fig 4: Q Penalty by OA1, OA2, And OA3

The fig4 shows the penalty placed on the NGP-ON2 networks by installing all optical amplifiers having 20 nm bandwidth in receiver filter. OA1 has low noise figure an gives the best performance. The graph shown above is free from ASE in OA1 then it contributes to the input of OA2, where internally generated ASE is generated. Since OA2 produces ASE, it must be compensated by OA1.

OA2 Upstream System Performance

Table 5 and fig 5 shows the upstream system performance by varying the optical amplifier2 output power and the BER is given below.

Table 5: OA2 Upstream performance by varying P_{sat}

Output Power of OA2	BER
-5	$0.79*10^{-1}$
-2.5	$0.35*10^{-1}$
0	$0.016*10^{-1}$
2.5	$7.94*10^{-4}$
5	$5.011*10^{-4}$
7.5	$3.16*10^{-4}$
10	$2.51*10^{-4}$
12.5	$1.99*10^{-4}$
15	$1.99*10^{-4}$
17.5	$1.99*10^{-4}$
20	$1.99*10^{-4}$

Since the input-signal power is lower than that of the output power in the upstream transmission path we have to optimize the saturation power Psat for each optical amplifier. The saturation power should be < −15 dBm. System performance increases by 3 dB as PSAT is increased from −5 to 9 dBm. Beyond 10 dBm, the performance levels off at *Q* ~ 11 dB. To maintain the system performance defined by OA1 PSAT, OA2 must be greater than 10 dBm.

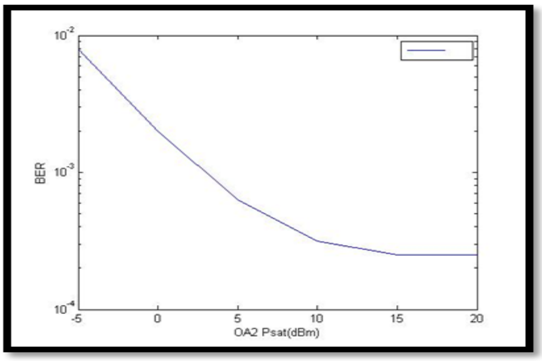

Fig5: OA2 Upstream performance by varying P_{sat}

Signal Shot Noise Power at the Receiver

Table6 and fig6 shows the noise power at the receiver, it is constant at -131 for varying receiver filter bandwidth.

Table 6. Signal Shot Noise Contribution Power At The Receiver

Receiver Filter Bandwidth [nm]	Noise Power [dBm]
0	-131
5	-131
10	-131
15	-131
20	-131
25	-131
30	-131

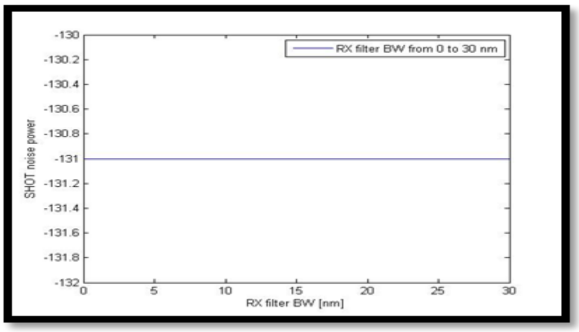

Fig 6: signal shot noise contribution power at the receiver

Thermal Noise Contribution Power at the Receiver

Table 7: Thermal Noise Contribution Power At The Receiver

Receiver Filter Bandwidth [nm]	Noise Power [dBm]
0	-116
5	-116
10	-116
15	-116
20	-116
25	-116
30	-116

Table 7 and fig 7 shows the thermal noise power at the receiver, it is constant at -161 for varying receiver filter bandwidth.

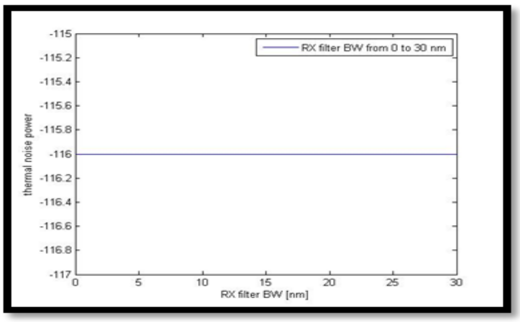

Fig.7: Thermal Noise Contribution Power at Receiver

ASE Noise Contribution Power at the Receiver

Table 8: Ase Noise Contribution Power At The Receiver

Receiver Filter Bandwidth [nm]	Noise Figure [dBm]
0	-155
5	-148
10	-146
15	-144
20	-142
25	-141
30	-140

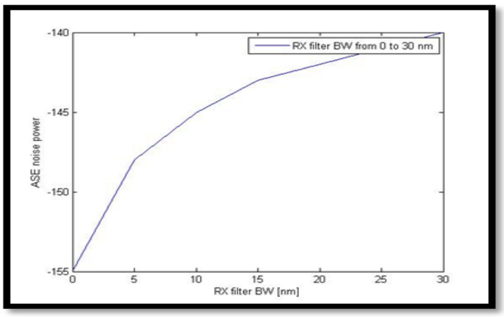

Fig 8: Ase noise power vs various filter bandwidth

Table 8 and fig 8 shows the ASE noise power at the receiver, it is varied with receiver filter bandwidth between 0 and 30 nm to adjust the ASE noise contribution.

Comparison of noise power

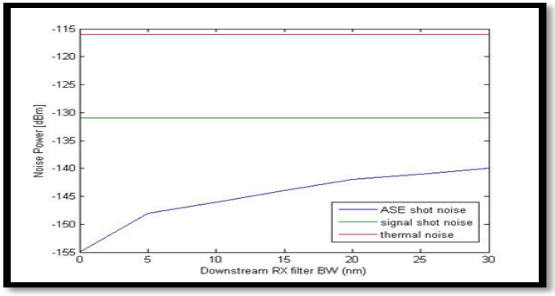

Fig.9: Comparison Of Noise Power

The fig 9 and table 9 shows the downstream noise modelling performed with the analytical model (transmitter output power, PTx = 0 dBm), illustrating each of the noise contributions as a function of the optical bandwidth at the receiver. Clearly, the thermal noise is the greatest contribution, although the “1” signal-spontaneous contribution is only 3 dB less. Since the system is thermal-noise limited, restricting the optical bandwidth by using optical filters at the receiver will have no effect on the system performance and the signal shot noise also have no effect on the system performance.

Downstream System Performance

TABLE9: DOWNSTREAM SYSTEM PERFORMANCE

Output Power of OA3	BER
10	$0.1*10^{-1}$
12	$0.25*10^{-2}$
14	$1.58*10^{-4}$
16	$2.511*10^{-6}$
18	$2.511*10^{-8}$
20	$6.30*10^{-10}$
22	$1.58*10^{-12}$
24	$6.306*10^{-14}$
26	$3.98*10^{-15}$
28	$1.8*10^{-15}$
30	$1.8*10^{-15}$

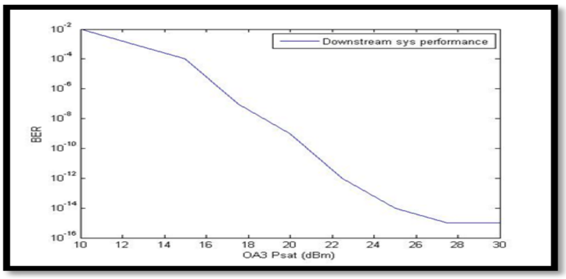

Fig 10 shows the output power of OA3 vs BER

Fig 10 shows the output power of OA3 is a critical parameter in defining the performance of the downstream transmission path. OA3 is situated prior to the distribution section. The total attenuation present in the distribution section, when the split size is 2048, is 40.3 dB. Such a large amount of attenuation is enough to ensure that ASE power emitted from OA3 is below the receiver noise power, as predicted in Fig.5.9. Therefore, to achieve the target performance, the signal power at the receiver must be greater than receiver sensitivity to overcome the thermal noise of the receiver, which defines the system performance in the absence of optical noise. As the sensitivity of the receiver, defined previously in Table I, is −20 dBm at BER = 10−10 to achieve the required performance of BER = 10−10, the output signal from OA3 must be greater than 20.3 dBm, as shown in the OptSim simulation results for OA3 given in graph above. Such a large output power does not cause any problems with nonlinear effects as OA3 is immediately followed by the optical splitters, and hence, the optical power is attenuated.

IV. Conclusion

The PON is design and development of a 2048-way-split 100km and 10-Gbps NGPON2 network in both upstream and downstream transmission. The eye diagrams are plotted for bidirectional data rate 10 Gbps. The transmitter frequency chirping factor “α_c” is tuned for different values to reduce the effect of dispersion. Best performance can be achieved when the frequency chirping factor “α_c” is less than -0.7. ASE is emitted by the amplifier in both the forward and reverse directions, but only the forward ASE is a direct concern to system performance since that noise will co-propagate with the signal to the receiver where it degrades system performance. Upstream transmission path performance was calculated with each optical amplifier’s saturation power is varied from -5 dBm to 20 dBm with Ptx is 4 dBm and optical amplifier gain 25 dB. To enables low BERs high optical power must be launched which provides high OSNR in the downstream path. The output signal from OA3 must be greater than 20 dBm for minimum BER of 10^{-9} with the sensitivity of the receiver to be −20 dBm,

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