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A Project Report on Downstream Transmission Performance of GPON

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Authors' contributions

This work was carried out in collaboration between all authors. Author AA designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Authors EP and MBH managed the analyses of the study. Authors HSM and KMAU managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This paper presents a Gigabit Passive Optical Networks (GPON) model which includes a power budget analysis, availability analysis and signal performance analysis of the system.
Study Design: A Gigabit Passive Optical Networks (GPON) model.
Place and Duration of Study: Department of Electronics and Communication Engineering, Khulna University, Khulna-9208, Bangladesh, between June 2017 and February 2018.
Methodology: The system performance is presented through various parameters such as Q factor, eye diagram.
Results: The proposed models have the nominal downstream bit rate 2Gbit/s with required bandwidth.
Conclusion: The model has very efficient packaging of user traffic, with frame segmentation to allow for higher QoS for delay-sensitive traffic such as voice and video communications.

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Keywords: GPON; Q factor; eye diagram; optisystem etc.

1. INTRODUCTION

Gigabit-capable Passive Optical Network (GPON) is the most important PON. The Time Division Multiplexing (TDM) technology was the basic technology for GPON. Gigabit Passive Optical Networks (GPONs) has been viewed as a promising technology for fibre-to-the-home (FTTH) optical systems because they can deliver multi-services (e.g. TDM, Ethernet) with the required Quality of Service (QoS) [1-5]. These services include multi-pattern triple-play services (voice, video, and data) that are bandwidth intensive [5-7]. Subsequently, bandwidth management with effective and fair QoS support becomes a test network designs. GPON is the successor to APON/BPON. It extends the capabilities of its two predecessors, asynchronous transfer mode (ATM) PON, and broadband PON (BPON) [1,8]. GPON systems can provide enough capacity for the next few years. GPON is the type of PON most widely deployed in today's fibre-to-the-home (FTTH) networks. Fiber-to-the-home (FTTH) networks are being installed in point-to-point (P2P) and point-to-multipoint (P2MP) time-multiplexed passive optical network (PON) architectures [9].The GPON transport protocol exploits TDM technique in the downstream and TDMA technique in the upstream direction [10].Most popular nowadays is the time-division multiple access (TDMA) protocol, where functions can be readily implemented with digital electronics. It is being used in BPON (ATM-based, up to 622 Mbit/s symmetrically), GPON (Gigabit PON, with speeds up to 1.224 Gbit/s, for ATM and also Ethernet packets plus native TDM), and EPON (Ethernet PON, optimized for variable-length Ethernet packets) [11]. GPON adopts a fixed duration frame structure (of 125μs), which can carry TDM traffic.[12] The gigabit passive optical network (GPON) is an outcome of the full-service access network (FSAN) alliance and is specified in the ITU-T G.984.x series of recommendations.[13] GPON provides larger splitting ratios, higher up- and downstream data rates, longer reach, improved privacy and security through the use of the Advanced Encryption Standard (AES) algorithm, and a new GPON encapsulation method (GEM) to carry synchronous voice services and data services [14] such as Ethernet in a bandwidth efficient manner. A GPON consists of an Optical Line Terminal (OLT) at the Central Office (CO) and Optical Network Units (ONU) for the local users of the network. The conventional Time Division Multiplexing (TDM) GPON standard specified by the ITU-T requires OLT broadcasting all downstream traffic to ONUs while ONUs time share upstream bandwidth. Hence, long queue delays emerge because different QoS requirements must be met using the upstream bandwidth. This can lead to congestion that quickly occurs when the traffic load is high. Hence, the hybrid TDM GPON offers effective bandwidth management and flexible QoS support towards a cost-effective architecture for next-generation optical access networks [14-15]. Finally, we have power budget analysis and signal performance analysis of the system. All necessary components are provided for detailed analysis.

2. EXPERIMENTAL DETAILS

The proposed architecture of the self-restored G-PON is shown in Fig. 1. GPON is a point-to-multipoint access mechanism. Its main characteristic is the use of passive splitters in the fibre distribution network, enabling one single feeding fibre from the provider's central office to serve multiple homes and small businesses. The proposed system can support up to 64 users at dedicated bandwidth 2.5 Gb/s per user/wavelength and channel spacing of 100 GHz. In GPON, there are three main components that provide communications from the distribution layer to access layer in a basic FTTD LAN configuration. This would be the Optical Line Terminal (OLT), Optical Distribution Network (ODN), also called the Optical Network Unit (ONU) in some cases, and Optical Network Terminal (ONT).

The first device at the distribution layer is the OLT. The OLT is the brain of the GPON FTTD LAN and provides the same functions of the layer three switches within the Cisco architecture plus more. This larger role is due to the nature of communications between the OLT and the ONT. All downstream communications from the OLT to the ONT is broadcast via TDM, while communications upstream from the ONT to the OLT is TDMA. The OLT not only routes all data between VLANs but also manages communications between systems within the same VLAN. The second device connecting the ONT to the OLT is the 1:64 splitter. The splitter is roughly the size of a cell phone and is a passive device which has no management, switching or routing capabilities (ITU-T, 2008a). It serves the same function as a layer two switch at the access layer in the sense of providing a communications link from the distribution layer to the access layer. Splitter as connecting multiple access layer ONT systems to the distribution layer OLT systems. This could be a topic of discussion as one splitter can have more clients than a switch or vice versa, but in theory, they perform the same function.

GPON supports several line rates for both the upstream and downstream directions and supports legacy ATM and packet-based transport, but also has an efficient Ethernet transport capability.

The detailed analysis of all the mentioned technologies is given in [11].

GPON standard defines a lot of different line transmission rates for downstream and upstream direction.

2.1 System Requirements

- Bit rate: 2.5 Gbps
- Transmission distance: 20 + 5 = 25 km
- BER: 10^{-10}
- Data format: NRZ
- Transmission type: Point to multi point (P2MP) — GPON

2.2 Types of Equipment and Specifications

For our proposed model, we require the following equipment.

Table 1. Transmission direction and Bit rate of standard GPON

Transmission direction	Bit rate
Downstream	1244.16 Mbit/s
	2488.32 Mbit/s
Upstream	155.52 Mbit/s
	622.08 Mbit/s
	1244.16 Mbit/s
	2488.32 Mbit/s

Avalanche Photo Diode (APD) – 66 pieces

Specification:

- Bit rate – 2.5 Gb/s
- Wavelength – 1260 to 1620 nm
- Bandwidth – 2.5 GHz
- Responsivity – 0.9
- Sensitivity – (-) 34 dBm at BER = 10 – 10
- Photo Current, Ip – 2x10 – 6 A
- Dark Current, Id – 10 nA (Max)
- Surface leakage current, IL = 2 mA
- Maximum insertion loss – 0.7 dB

Single mode optical fiber (SMF) – 20 + 5 = 25 km

Specification:

- Center Wavelength – 1550 nm
- Attenuation – 0.18 dB/km
- Water immersion induced attenuation – 0.05 dB/km
- Waveguide dispersion – ≤ 18 ps/nm-km
- PMD Dispersion – ≤ 0.2 ps/nm-km1/2
- Bending loss (100 turns) – 0.05 dB
- Mode field diameter – 11 µm
- Cladding diameter – 125 µm
- Effective group refractive index – 1.467

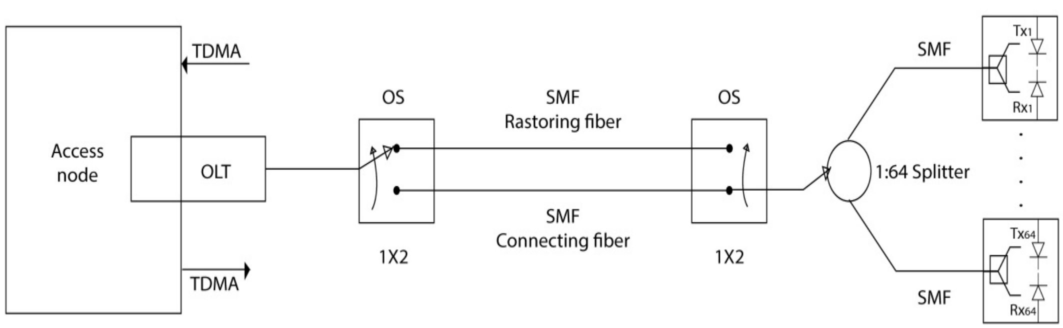

Fig. 1. The architecture of the proposed GPON

CW laser -64 pieces

Specification:

- Bit Rate – 2.5 Gb/s
- Center Wavelength – 1490 nm
- 3-dB bandwidth – o.4 nm
- Threshold current – 10 mA at 250C
- Output power – 5 mW = 7 dBm
- Source connector loss – 0.5 dB
- Rise time – 100 ps

Splitter – 1 piece

Specification:

- Bit rate – 2.5 Gb/s
- Wavelength – 1310nm and 1550nm
- Channel Spacing – 100 GHz
- Number of Channels – 64
- 3-dB bandwidth – 40 nm
- Maximum insertion loss – 2.1 dB

Optical Attenuator

Specifications:

- Wavelength : 1310 / 1550±40 nm
- Insertion loss: 1 to 5 db ±0.75
- Return loss: PC > 45 dB: APC > 65 dB
- Temperature ranges and humidity: Storage temperature : -55°C to 80°

FC connector – 68 pieces

Specification:

- Center Wavelength – 1550 nm (SMF)
- Insertion loss – 0.2 dB (SMF)
- Durability (Hours) – >1000

Optical circulator (OC) – 64 pieces

Specification:

- Wavelength – 1520 nm to 1625 nm
- Insertion loss – 0.8 dB
- PDL loss – 0.15 dB

Optical switch (OS) (1x2) – 2 pieces

Specification:

- Wavelength – 1520 nm to 1625 nm
- Insertion loss – 1 dB (SMF)
- PDL loss – 0.1 dB
- WDL loss – 0.3 dB
- Switching speed – 5 ms

3. RESULTS AND DISCUSSION

3.1 Transmitter Selection

For our proposed architecture, we need single mode laser diode for each user that can operate at 2.5 Gb/s in the C band. The channel spacing is about 100 GHz. That's why we selected CW laser with a central wavelength of 1490 nm having the same wavelength.

3.2 Optical Splitter

The optical splitter split the input signals receiving from the laser and provide to the outputs. In this project, we proposed for 64 users and simulate for 4 users in optic system 13.0 Software.

3.3 Optical Receiver Selection

We selected ADP with sensitivity (MRP) of -34 dBm. The photo current, Ip = 2 μA. Now the minimum detectable power (MDP) is:

MDP = Po = *Ip/R*

[where R = 0.9 is the responsivity of the APD]

Therefore, MDP = 2/0.9 = 2.22 μW = – 27 dBm
Now minimum detectable Power (MDP) can be calculated as:

$$\text{MDP}= \frac{Q}{r}\left\{QeF(BR)J_1 + \left[\frac{\langle i_{NA}^2\rangle}{G^2} + 2eI_{dm}F(BR)J_2\right]^{1/2}\right\}$$

[Q = 3.0554 from Fig. 2]

Where, $\langle i_{NA}^2\rangle = \frac{4k_BT(BW)}{R_i}$

So, MDP ≈ - 17 dBm, which is equal to the data sheet value.

We know that,

MRP = MDP + Loss
Or, - 34 = -17 + Loss
Or, Loss = - 17 dB
Optical fiber Selection:

3.3.1 <u>Numerical aperture and core diameter calculation</u>

Refractive index of core, η_1 = 1.47
Refractive index of cladding, η_2 = 1.465
V number, V = 2.405 (for single mode fiber)
Center Wavelength, C = 1550 nm = 1.55 μm
Let, the core radius is = a

We know that, cut-off wavelength,

$$\lambda_C = \frac{2\pi a}{V}(\eta_1^2 - \eta_2^2)^{1/2}$$

$$a = \frac{\lambda_C \times V}{2\pi \times (\eta_1^2 - \eta_2^2)^{1/2}}$$

Or, a = (1.55×2.405)/ (2×3.14×0.12)
Or, a = 4.95 µm

Therefore, the diameter of the core is R = 2×a = 9.9 µm
Numerical aperture, NA = $(\eta_1^2 - \eta_2^2)^{1/2}$=0.12

3.3.2 Waveguide dispersion calculation

The waveguide dispersion can be calculated as,

$$D_{WG}(\lambda) = -\frac{\eta_{2\Delta}}{c}\frac{1}{\lambda}\left(V\frac{d^2(Vb)}{dV^2}\right)$$

From Fig. 3.15 of Keiser, Optical Fiber Communication, we find that for V= 2.405, $\frac{d^2(Vb)}{dV^2}$=0.5

3.3.3 Polarization mode dispersion

The value of the polarization mode dispersion is given in the data sheet as 0.20 ps/nm-km ½.

3.3.4 System Performance analysis

A) Signal-to-noise ratio calculation

The signal-to-noise ratio (S/N) for the proposed system can be calculated as:

$$\frac{S}{N} = \frac{I_P^2 M^2}{2q(I_P + I_D)M^2 F(M)B + 2qI_L B + \frac{4k_B TB}{R_L}}$$

Here,

Photo Current, IP = 2 µA = $2 \times 10^{-6}\ A$
Dark Current, ID = 10 nA =$10 \times 10^{-9}\ A$
Surface leakage current, IL = 2 mA = $2 \times 10^{-3}\ A$
Charge of electron, $q = 1.6 \times 10^{-19}\ C$
Gain of APD, M = 10
Noise Figure, F(M) = Mx = $10^{0.7}$= 5
[considering x = 0.7]
Bandwidth, B = 2.5 GHz = 10^9 Hz
Boltzman's constant, k_B = 1.38×10^{-23} J/K
Temperature, T = 293K
Load resistance, R = 15 kΩ = 15×1000 Ω

Therefore, S/N = 38.01 = 15.8 dB
From Fig. 2, we find that for S/N of 22.2 dB, the value of Q is ≈3.055 and the BER is≈1.01×10^{-3}. From the system specification, we find that the BER in the range of 10^{-3}, which matches the calculated value of BER.

B) Rise time calculation

The allowable maximum rise time can be calculated as:

$t_{sys} = 0.7/ B_{RNRZ} = 0.7/2.5$ Gbps = 0.28 ns

But practically, the system rise time can be calculated as:

$t_{sys} = [\, t_{tx}^2 + t_{GVD}^2 + t_{mod}^2 + t_{rx}^2 \,]^{1/2}$

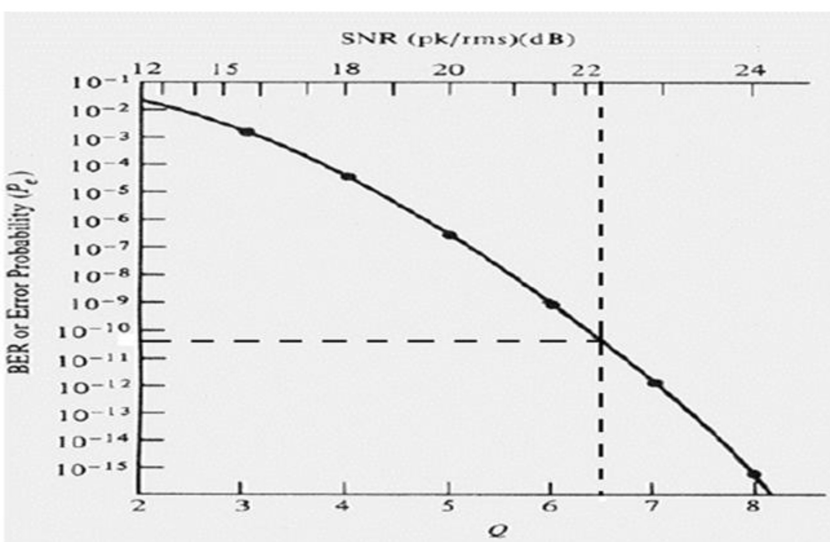

Fig. 2. The graph for BER as a function of signal-to-noise ratio and Q

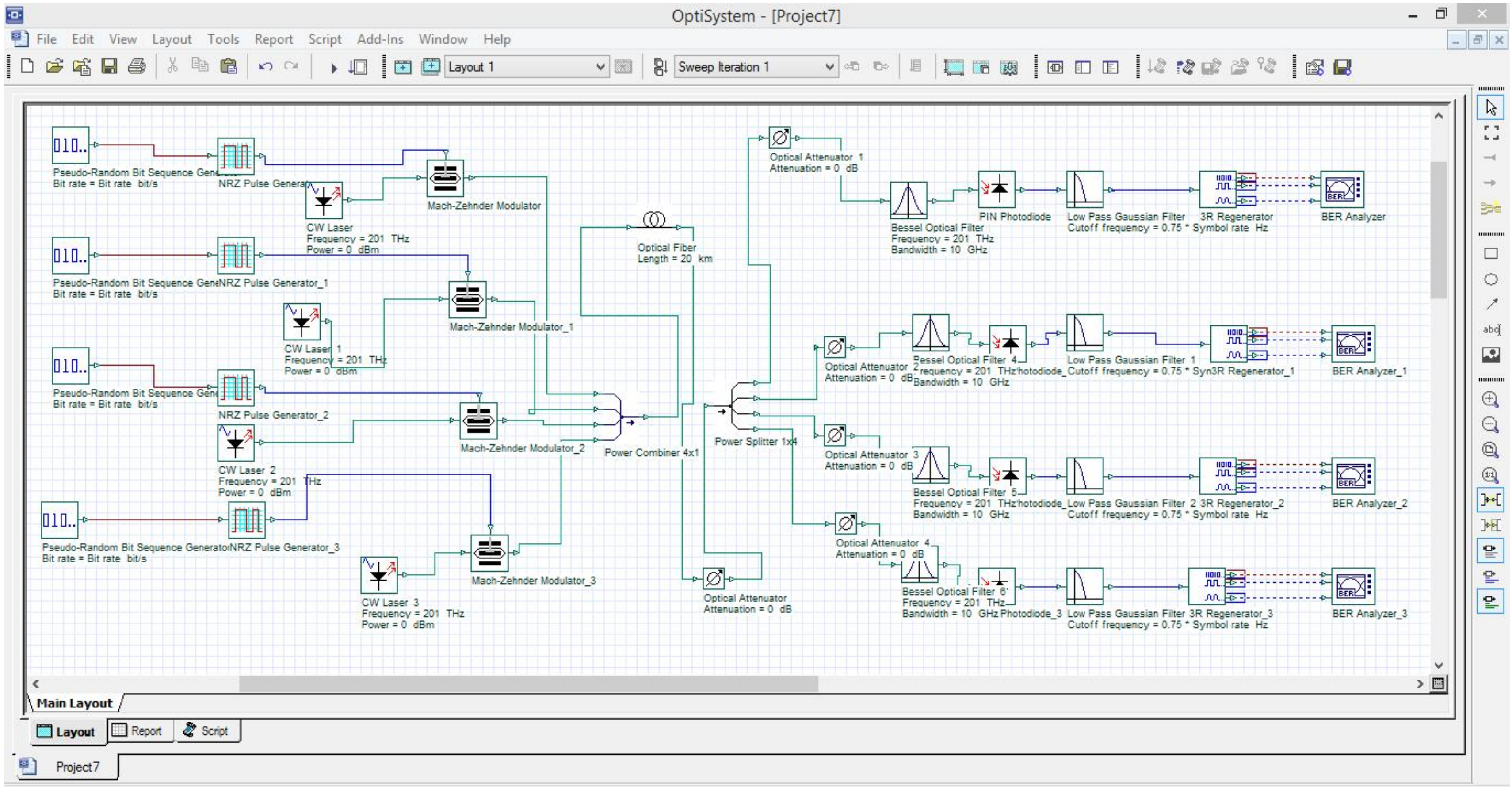

Fig. 3. GPON Downstream Simulation Model in Optisystem 13.0 Software

As we are using single-mode fibre, we can neglect the modal dispersion rise time $t_{mod.}$

Now the transmitter rise time, t_{tx} = 100 ps = 100×10^{-12} s

The receiver rise time,

$t_{rx} = 350/B_{rx}(MHz)$

So, $t_{rx} = 350/2500 = 0.14$ ns $= 0.14\times10^{-9}$ s

Fiber rise time,

$t_{GVD} = |D|L\sigma$ [σ = 0.4 nm, |D| = 18ps/nm-km, L = 25 km]

So, t_{GVD} = 180 ps = 180×10^{-12} s

Therefore, t_{sys} =

$$\sqrt{(100\times10^{-12})^2+(180\times10^{-12})^2+(0.14\times10^{-9})^2}$$

Or, t_{ry} = 0.25 ns

Which is less than the allowed rise time.

C) Simulation result

A simulation has been performed using OPTISYSTEM 13.0 software for finding the eye diagram during the downstream transmission. The circuit diagram is shown in Fig. 3.We performed the experiment using 1490 nm wavelengths.

The input spectrum and output eye diagram are shown in Fig. 4.

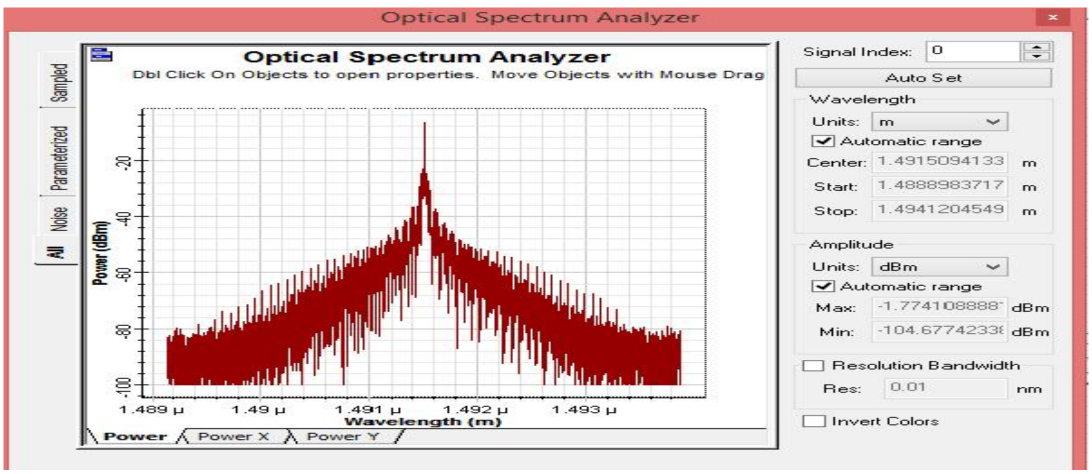

Fig. 4(a). Input Spectrum

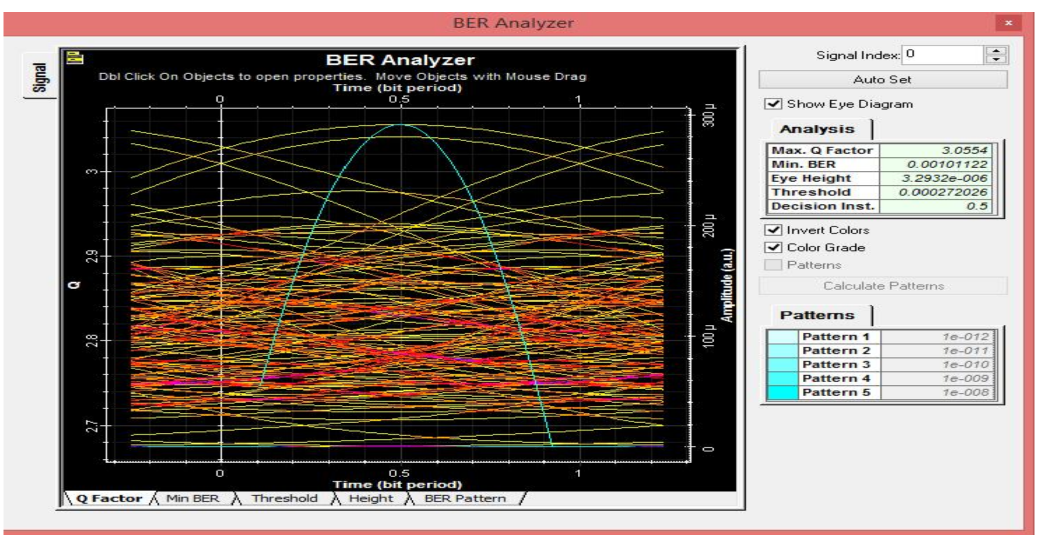

Fig. 4(b). Output eye diagram showing Q factor

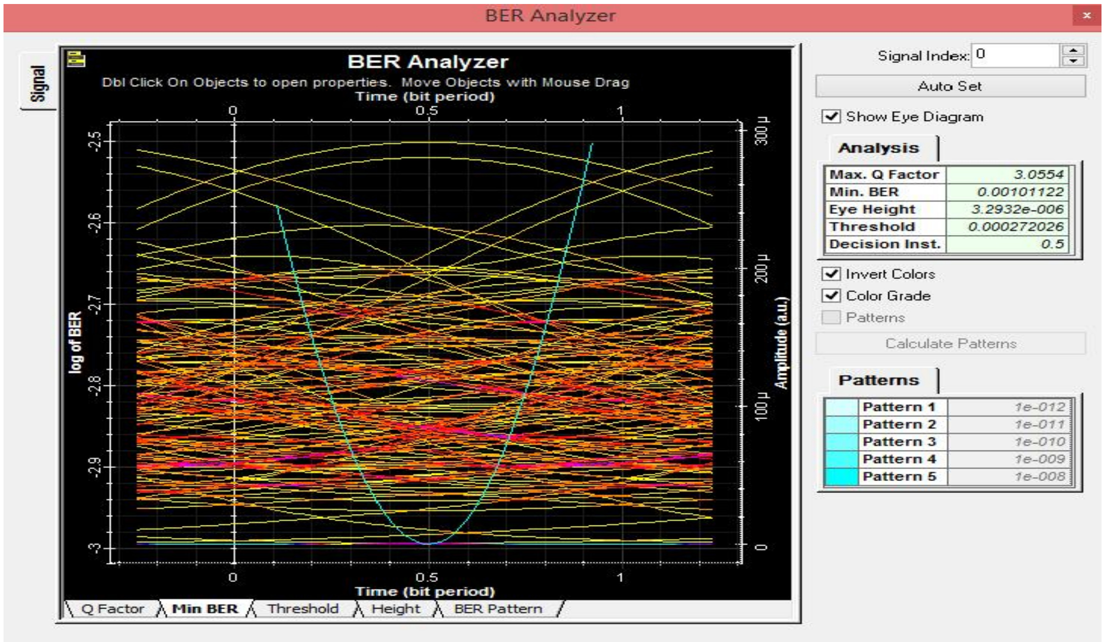

Fig. 4(c). Output eye diagram showing Min BER

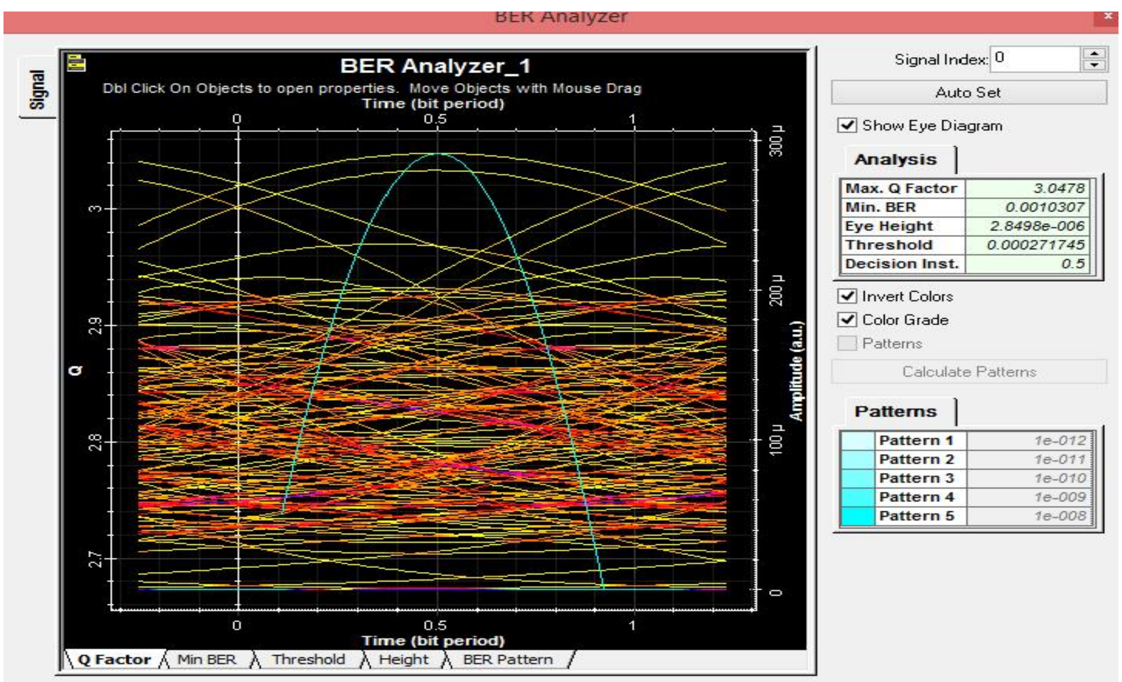

Fig. 4(d). Output eye diagram showing Q factor at high attenuation rate

3.3.5 The system availability analysis

The performance of the proposed system is quantified by calculating the system availability. The System unavailability U can be obtained as follows:

$$U = MTTR / MTBF$$

The System availability A can be obtained as follows:

$$A = 1 - U$$

Where MTTR and MTBF represent mean-time-to-repair and mean-time-between-failure respectively. The model for calculating the system availability is shown in Fig. 5. The values for calculating MTTR and MTBF are found in Table 2 [12,13].

For the proposed restorable GPON, overall unavailability of a channel is calculated by the sum of the un-availabilities of an OLT, feeder fibre, an OS, an AWG, a distribution fibre, and an ONU. Un-availability of OLT is calculated by the sum of the un-availabilities of a transmitter and receiver, filter, a Splitter and one OS. The un-availability of one ONU can be calculated by the sum of the un-availabilities of transmitter & receiver, and 3-dB optical splitter.

So, un-availabilities of restorable GPON are as follows:

$$U_{OLT\text{-}GPON} = U_{Tx} + U_{Rx} + U_{OC} + U_{Splitter} + U_{OS} = 3.62\times10^{-7} + 1.4\times10^{-7} + 4\times10^{-7} + 4\times10^{-7} + 4\times10^{-7} = 17.02\times10^{-7}$$

$$U_{Overall\text{-}GPON} = U_{OLT} + U_{FF} + U_{OS} + U_{Splitter} + U_{DF} + U_{ONU} = 17.02\times10^{-7} + 547.9\times10^{-7} + 4\times10^{-7} + 4\times10^{-7} + 137\times10^{-7} + (3.62\times10^{-7} + 1.4\times10^{-7} + 4\times10^{-7}) = 718.94\times10^{-7}$$

So, the availability of the restorable GPON is,

$$A_{Overall\text{-}GPON} = 1 - U_{Overall\text{-}GPON} = 1 - 718.94\text{x}10^{-7} = 0.9999282$$

3.3.6 Power Budget calculation

The power budget calculation of the proposed architecture is given in a tabular form in Tables 3 and 4.

Table 2. FIT, MTTR, MTBF and Un-availability of elements

Elements	FIT (failures/10^9 hours)	MTTR (hours)	MTBF (Years)	Un-availability
Tx	186	2	630	3.62×10^{-7}
Rx	70	2	1630	1.4×10^{-7}
Optical switch (OS)	200	2	570	4×10^{-7}
Splitter	200	2	570	4×10^{-7}
Optical circulator (OC)	200	2	570	4×10^{-7}
Optical splitter (O3-dB)	200	2	570	4×10^{-7}
Feeder Fiber (20 km)	2280	24	50	547.9×10^{-7}
Distribution Fiber (5 km)	570	24	200	137×10^{-7}

Table 3. Spreadsheet for calculating the power budget for downstream transmission of the proposed GPON

Component/loss parameter	Output/sensitivity/loss	Power margin (dB)
Laser output	7 dBm	
APD sensitivity at 2.5 Gb/s	– 34 dBm	
Allowed loss [7 – (– 34)]		41
Source connector loss	0.5 dB	40.5
Circulator loss	0.95 dB	39.55
Splitter loss	2.1 dB	37.45
Optical switch loss (two)	2.8 dB	34.65
Cable attenuation (25 km) and other losses	5.8 dB	28.85
FC Connector loss (four)	0.8 dB	28.05
3-dB coupler loss	0.25 dB	27.8
Insertion loss of Receiver	0.7 dB	**27.1 (Excess power)**

Table 4. Spreadsheet for calculating the power budget for upstream transmission of the proposed GPON

Component/loss parameter	Output/sensitivity/loss	Power margin (dB)
R-SOA Output	4 dBm	
APD sensitivity at 1.25 Gb/s	– 34 dBm	
Allowed loss [7 – (– 34)]		38
Source connector loss	0.5 dB	37.5
Circulator loss	0.95 dB	36.55
Splitter loss	2.1 dB	34.54
Optical switch loss (two)	2.8 dB	31.74
Cable attenuation (25 km) and other losses	6.8 dB	24.94
FC Connector loss (four)	0.8 dB	24.14
3-dB coupler loss	0.25 dB	23.89
Insertion loss of APD	0.7 dB	**23.19 (Excess power)**

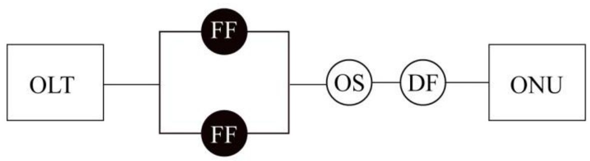

Fig. 5. The schematic architecture of proposed GPON for calculation of availability

4. CONCLUSION

This proposed GPON model provides a power budget analysis, availability analysis and signal performance analysis of the system and it has the nominal downstream bit rate 2Gbit/s with required bandwidth. Hopefully, this model can be implemented practically which will give us very efficient packaging of user traffic, with frame segmentation to allow for higher QoS for delay-sensitive traffic.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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