Design Simulation of Raman Amplification Hybrid XGPON System with RZ and NRZ Data Format

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Abstract

Next-generation Passive Optical Networks (PONs), which are considered one of the most encouraging optical access networks, has remarkably developed in the past few years and intended to greatly go forward in the nigh future. By this development the power requirements of NGPON will growth and make it no longer coveted. This paper presents Hybrid (WDM/ TDM) XGPON architecture, where in this optical fiber communication system a bidirectional optical fiber has been applied with downstream and upstream NRZ and RZ (0.6 and 0.8 duty cycle)Data Format transmission. Distributed Raman amplification is employed for upstream signal for improving the loss budget of XGPON system. Fiber attenuation, splice losses, and back-reflections as in realistic fiber plant have been considered for this XGPON system. These impairments effects on 1270 nm upstream Raman amplified signal XGPON system have been investigated numerically.

Keywords: GPON, XGPON, Hybrid (WDM/ TDM), Raman Amplification

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1. Introduction

The growth of the Internet has led to a variety of modern applications which need access to high-speed networks causing to the making of bandwidth intensive Applications which require deterministic latency and low jitter [1]. Gigabit Passive Optical Networks (GPONs) have been lately prevailed universally and are looked forward to playing an essential role for carrying subscribers' needs of higher data rate. PONs are a communication networks have no active elements along signal's pathway ,where only passive optical components are used as external elements such as the optical fiber, splitters and splices. PON comprises of an Optical Line Termination OLT, a passive splitter and Optical Network Unit ONUs [2]. The primary ONUs occupation is to obtain optical traffic and transform it to the customer's preferred format such as IP multicast, Ethernet, POTS, etc. Figure 1 shows logical network architecture of different Fiber to the x technology (FTTx), which x recognize as building, cabinet, node, cell or even home [3].

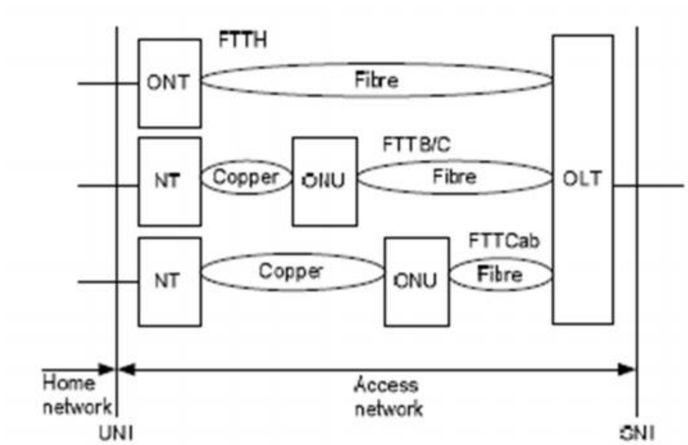


Figure 1 FTTx network architecture [3]

2. Gigabit-capable Passive Optical Network (GPON)

The Gigabit Passive Optical Network is kind of the Passive Optical Network (PON) that is commonly prevailed in today's (FTTH) networks.

Active transmission gear in GPON network involves merely of Optical Line Termination (OLT) and Optical Network Unit (ONU). Fiber to the home network (FTTH) is being set up in point to point (P2P) and point to multipoint (P2MP) time multiplexed Passive Optical Network (PON) architectures. The Gigabit Passive Optical Network conveyance protocol utilizes the TDMA technique in the upstream and TDM technique in the downstream path [4].Most widespread these days is the protocol of the Time Division Multiple Access (TDMA) as jobs is being carried out with digital electronics. GPONs provide bigger splitting ratios, superior downstream and upstream data rates, lengthier reach, upgraded the security and the privacy via the usage of a new GPON Encapsulated Method (GEM) and Advanced Encryption Standard (AES) algorithm for conveying data services and synchronous voice services like (Ethernet) in a bandwidth efficient manner [5].

In the beginning at the central office (CO), merely one optical fiber (single mode) participates to a passive optical power splitter nearby users sites as shown in figure (2). Afterward, the optical power is divided simply to N separated trails by splitting device to the subscribers at the optical splitter. The number of splitting pathways be able to fluctuate from [2 – 64]. The optical fiber can be devoted from optical splitter to each user (businesses, home, etc.). The length of the transmitted fiber optic can be extended up to 20 km from the central office to every user [2].

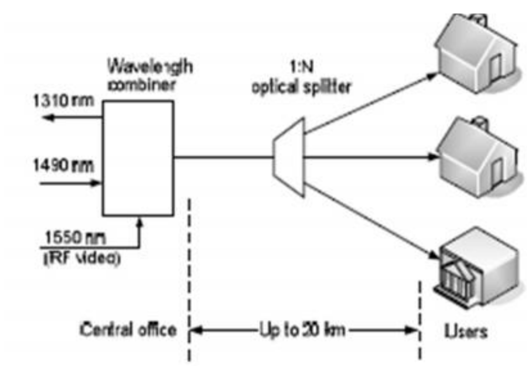


Figure 2 Typical GPON architecture [2]

The modern circulation in America and Europe continents is based on the GPON optical system that is normalized via the (ITU-T series G.984)

[3]. It normally can be serve up to 64 workers with 1.2 Gbit/s upstream speed and 2.4 Gbit/s downstream speed. Since the communicated fiber optic as a mass media be able to conveyance a lot, the technology of FTTH is expected to give more to operators. The ITU-T has issued recently the current GPON as upcoming benign speculation of 10 Gigabit Capable Passive Optical Networks (XGPON1) as contemporary standard for first generation [4]. Speed of 2.5 Gbit/s upstream and speed of 10 Gbit/s downstream will be presented by this modern standard, nevertheless the split ratio and the intended distance did not grow a lot. The research of this area keeps on the work to get even the better (P2MP) technology. A lot of them are nowadays identified as second generation for following generation Passive Optical Network (NGPON2).

3. WDM-TDM Hybrid PON

Hybrid PON (WDM-TDM) is the system that utilizes both WDM and TDM techniques. The benefits of both multiplexing techniques are supplied to the ending users. Various wavelengths in this architecture are exercised to recognize communication between the number of ending users and the Central Office (CO). This communication is achieved in two stages. Initially, several wavelengths are allocated to various Optical Network Units (ONUs) clusters. Every wavelength will be assigned on time basis by numerous Optical Network Units (ONUs) of the same cluster. The whole wavelength is partitioned into number of wavelengths by WDM technique. Every wavelength is assigned by a group of number of the Optical Network Units (ONUs) by using TDM technique and so on [3].

4. Distributed of Raman amplification

Distributed of the Raman amplification has been recommended to get well the impairments budget and develop the access of XGPON network. So as to conserve the outer optical fiber passive in complete form, the Raman pumped signal can be located by the side of the central office (CO) to feed the feeder optical fiber by distributed gain for upstream signal, whereas a semiconductor optical amplifier (SOA) or a high power signal source can be utilized for downstream signal. Nonetheless, the advantages of the distributed Raman amplification might be diminished because of the losses of splices and fiber losses which is leaded to lower Optical Signal to Noise Ratio (OSNR) and lower Raman gain [6].

Furthermore, the Multiple Path Interference (MPI) might be caused by the back reflections at the splices, hence, the signal integrity endures further degrading. The enumeration of extra impairments produced by non-ideal conditions that is mentioned above is very important and assess the performance of the Raman amplified GPON as well as XG-PON extended system with pragmatic optical fiber limits [7].

5. Modeling

In this paper, the OSNR degradations are investigated numerically for upstream signal that produce by raising the attenuation of the fiber, losses of splices and the Raman amplified XG-PON reach extender back-reflections. A design solution able to 60 km logical reach and splitting ratio of 1:64 is presented by utilizing the considerations of an employed XGPON system. The XGPON system modeling that considered in this work is shown in the Figure (3). The designed system using OPTISYSTEM software (2013) is presented in Appendix A and the flowchart is shown in in the Figure (4). A CWDM coupler at the Central Office combines the Raman pump upstream signals for the 1270, 1310nm as well as downstream signals for the 1490, 1577 nm and send them to 60-km feeder optical fiber. An SOA enhances the 1490, 1577 nm signal power. The signal of 1270, 1310 nm inputs to the feeder optical fiber next to passing through a CWDM coupler of Optical Network Unit (ONU) and a 1: N power splitter at the Remote Node (RN).

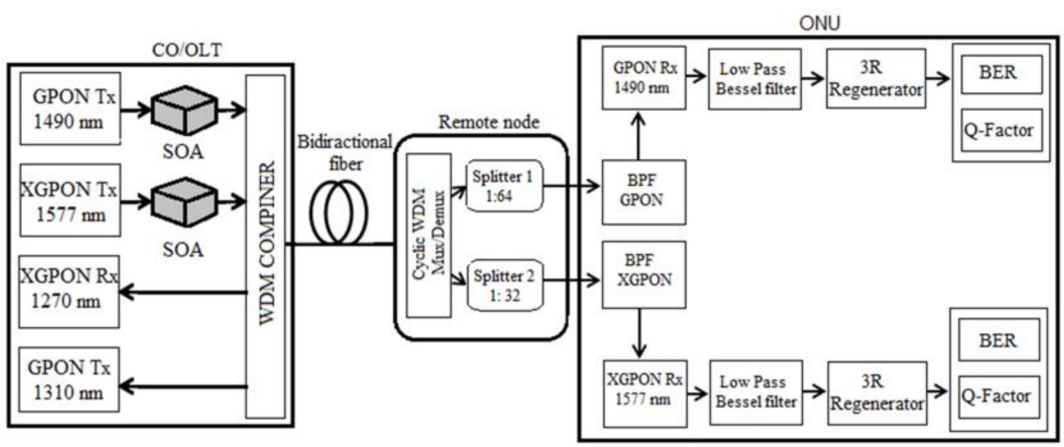


Figure 3 system setup

The GPON downstream transmitter is implemented using Distributed Feedback laser diode that has power of 3dBm in RZ and NRZ data format for 1490nm. The XG-PON downstream transmitter is implemented using electro-absorption modulated laser(EML) of power = 0 dBm in RZ and NRZ data format for 1577nm with 10 Gb/s transmission. The bandwidth between the 1260 nm to the 1280 nm for the upstream and the 1575 nm to the 1580 nm for the downstream transmission of the XGPON is selected by the FSAN/ITU-T collection, As particular requirements of the optical transceiver in marketplace and manufacturing. The 5 nm wide is chosen for downstream window, using this narrow band for cooling laser supplies and making the wavelength stable. The 20 nm wide is chosen for upstream window, the uncooling laser sources can be employed and the ONUs expenses reduced.

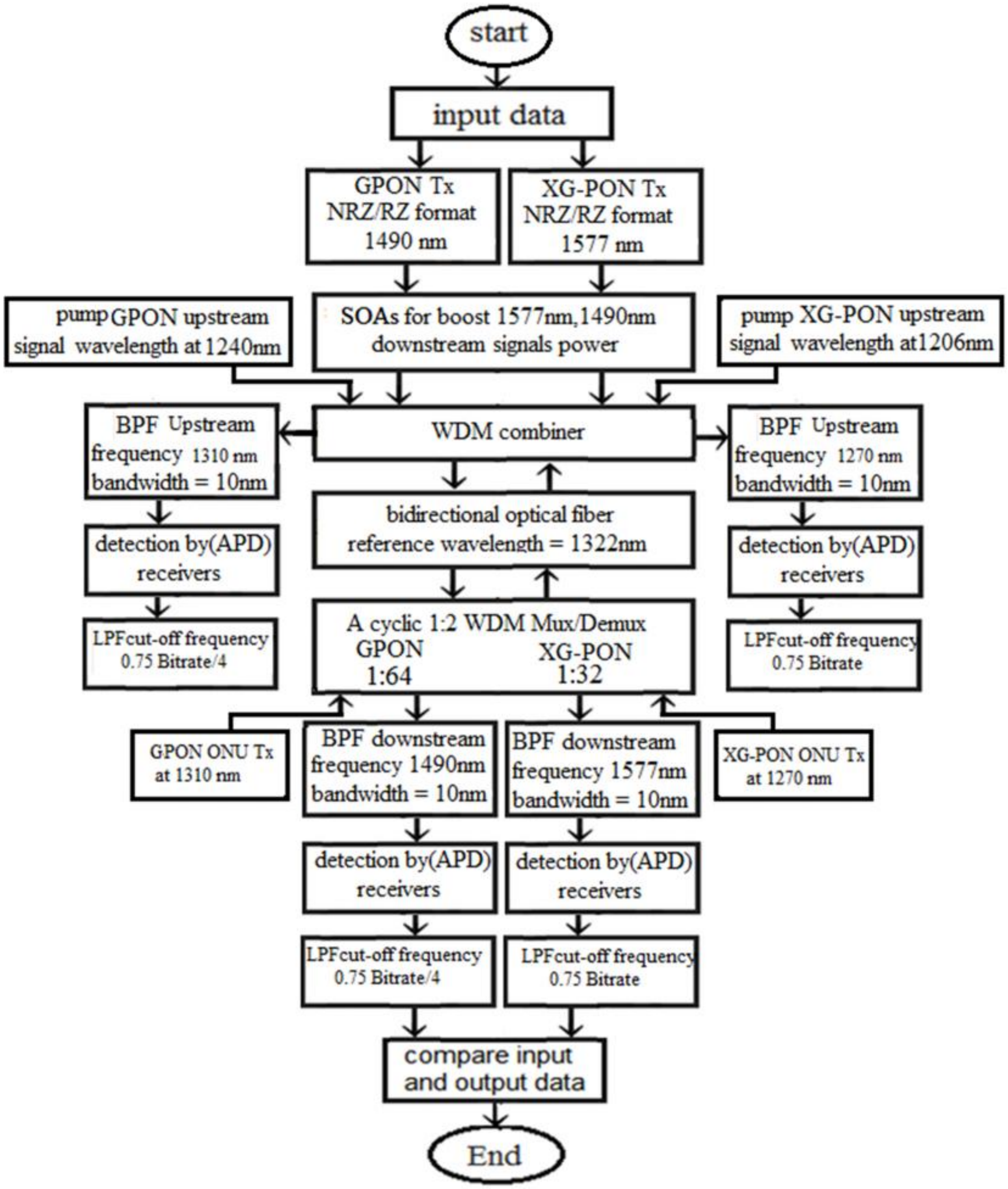


Figure 4 System flowchart

Semiconductor optical amplifiers SOAs are used for integrating the downstream transmitter to enhance both 1490nm and 1577nm signal powers with 15 dBm and 16 dBm saturated power singly to put up high loss funds for extensive reach. In order to decrease pattern dependent distortion by reason of the earn dynamics of the SOA, these SOAs are functioned in a linear organization. For providing distributed Raman gains to GPON upstream signal band from1300 nm to 1320nm besides to XGPON upstream signal band from 1260 nm to 1280 nm two pump signals with wavelength 1240nm of power equal to 520mW and 1206nm of power equal to 850mW respectively are treated to be combined into the feeder fiber.

For combining the GPON /XGPON downstream signals and drive lasers and splitting them a WDM combiner is used. As distinct in the ITU-T norms the WDM combiner is designed to guarantee the wavelength organization requirements together with the compatibility for GPON /XGPON signals. For improving the transmission performance the WDM combiner can be used for filtering out the unwanted Raman noise (ASE) outer the bands of upstream signal. The reference wavelength is 1322 nm between 1300nm and 1324nm has zero dispersion for bidirectional optical fiber with dispersion slope equal to 0.086 ps/nm2/km. the attenuation and fiber nonlinearity (Self phase Modulation and Cross phase Modulation) effects are taking into account. A combination of 1:32 and 1:64 optical splitters of cyclic 1:2 WDM Mux/Demux for XGPON and GPON respectively is employed in the Remote node (RN).

Each ONU have band pass filter having bandwidth equal to 10nm of frequency 1490nm for GPON downstream and 1577nm for XGPON downstream. Avalanche Photo detector (APD) is used in the receivers for signal detection at 1490nm and 1577nm. After that the signals is passed in two LPFs of 3 dB cut off frequency which is equal to 0.75 Bitrate/4 for GPON and 0.75 Bitrate for XGPON. In order to renew the electrical signal 3R regenerator is employed that can be tied to the BER analyzer directly.

A group of coupled steady state equations as presented in equation 1 which are based on the standard model of distributed Raman amplification are used to describe the propagation of the signal, their backscattered powers, pump signals and the noise channels in the bidirectional feeder fiber [9].

$$\frac{d}{dz}P^{\pm}(z,\nu_i) = \mp\alpha(\nu_i)P^{\pm}(z,\nu_i) \pm \gamma(\nu_i)P^{\mp}(z,\nu_i)$$
$$\pm\sum_{m=1}^{i-1} C_R(\nu_m-\nu_i)\left[P^{\pm}(z,\nu_m)+P^{\mp}(z,\nu_m)\right]\left\{P^{\pm}(z,\nu_i)+2h\nu_i\left[1+\frac{1}{e^{h(\nu_m-\nu_i)/KT}-1}\right]\Delta\nu\right\}$$
$$\mp\sum_{m=i+1}^{n}\frac{\nu_i}{\nu_m}C_R(\nu_i-\nu_m)P^{\pm}(z,\nu_i)\left[P^{\pm}(z,\nu_m)+P^{\mp}(z,\nu_m)\right]$$
$$\pm\sum_{m=i+1}^{n}\frac{\nu_i}{\nu_m}C_R(\nu_i-\nu_m)\left[2h\nu_i\left(\frac{1}{e^{h(\nu_i-\nu_m)/KT}-1}\right)\Delta\nu\right]\left[P^{\pm}(z,\nu_m)+P^{\mp}(z,\nu_m)\right]$$
$$\mp\sum_{n=1}^{L/L_{sp}}\alpha_{sp}P^{\pm}(z,\nu_i)\delta(z-nL_{sp}) \pm \sum_{n=1}^{L/L_{sp}}\alpha_r P^{\mp}(z,\nu_i)\delta(z-nL_{sp}) \text{ ....Eq.(1)}$$

In the above equation, P^+ (z,ν $_i$) and (,) P^- (z ,ν $_i$) are the optical powers of the forward- and backward-propagating waves within the bandwidth Δν , respectively. The fiber loss coefficient is represented by α, whereas the recaptured Rayleigh backscattering is given by the coefficient γ. The Raman gain efficiency is $C_R \equiv g_R / A_{eff}$, where g_R is the Raman gain coefficient scaled to the pump wavelength, and A_{eff} is the effective mode area. The coefficients h and k are Planck's constant and Boltzmann's constant, respectively, whereas T is the fiber temperature. Both the spontaneous emission (in the third term) and the absorption (the fifth term) are included in the model, with the factor of 2 accounting for the two polarization modes of the fiber. For stimulated emissions, the optical powers at frequencies from m = 1 to m = i – 1 amplify the signal at frequency I ν, whereas the optical powers at frequencies from m = i + 1 to m = n attenuate the signal. The frequency ratio ν_i / ν_m ensures photon conservation. The pumps are polarization scrambled. The last two terms correspond, respectively, to losses and back-reflections at splices, with α_{sp} being the splice loss, α_r the return loss, L_{sp} the length of each spliced fiber segment, and L the total length of the feeder fiber [10].

6. Results and discussion

This paper presents coexistence of XGPON in addition to GPON for (60 km) propagation. SOAs are used for downstream signals and for upstream signals Raman amplification is used. In this work the performance of 10 XGPON system for RZ and NRZ format has been introduced. In order to evaluation the performance eye diagrams, Q factor and BER are being taken into consideration for both GPON and XGPON. Q factor as a function of span for RZ (duty cycle = 0.6 and 0.8) as well as NRZ downstream signals for GPON as well as XGPON correspondingly are presented in figures (5, 6). Figure 5 shows a comparison between RZ and NRZ transmission, RZ format accomplishes better than NRZ since system receiver and launches the average power are improved by RZ data format. Peak power limits the effects of SPM and XPM in the bidirectional fiber.

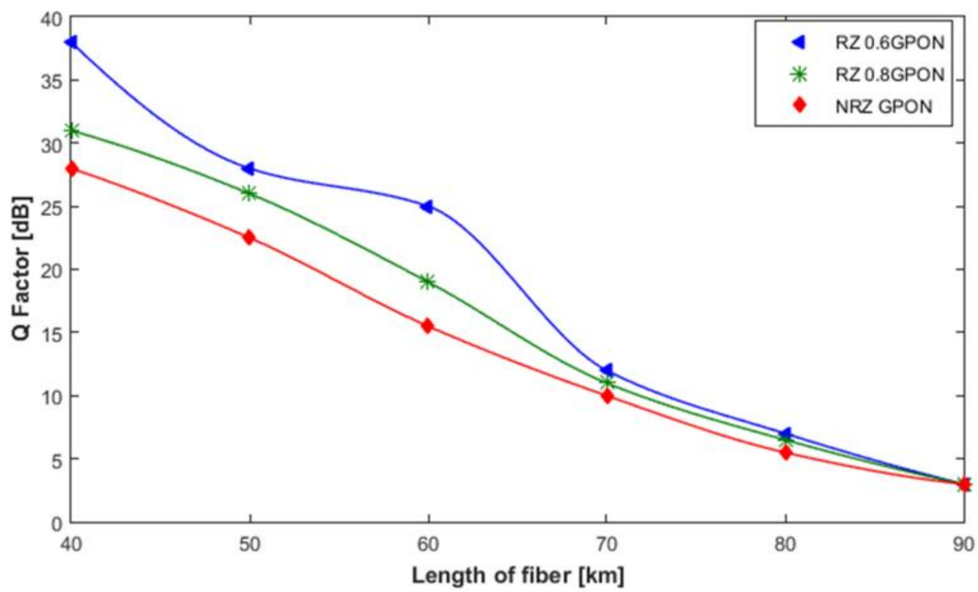


Figure 5 graphical depiction of the Q value for RZ and NRZ downstream transmitted data for GPON.

On the other hand a high peak power of RZ pulses produce SPM and XPM. These RZ pulses can endure compression and achieve finer than NRZ pulses. In in downstream communication for 0.6 RZ pulses the Q factor is about 27.4 dB and 12.5 dB at a distance of 50 km and 70 km. for

NRZ and RZ pulses system performance is the same after 70 km distance as at higher length there is no impact of these data formats in event GPON system .

For XGPON system RZ is again better than NRZ format as shown in figure (6). For XGPON at a distance of 50 km as well as 70 km the Q factor acquired is 9.6 dB and 8.5 dB correspondingly in the downstream transmission of 0.6 RZ format. Due to fiber attenuation and nonlinearities effects Q factor declines with the increase of fiber length. In 0.6 RZ downstream transmission of XGPON the authentic transmission distance is up to 85 km, where at BER 10^{-9} the lowest tolerable Q factor is 6 dB for dedicated transmission.

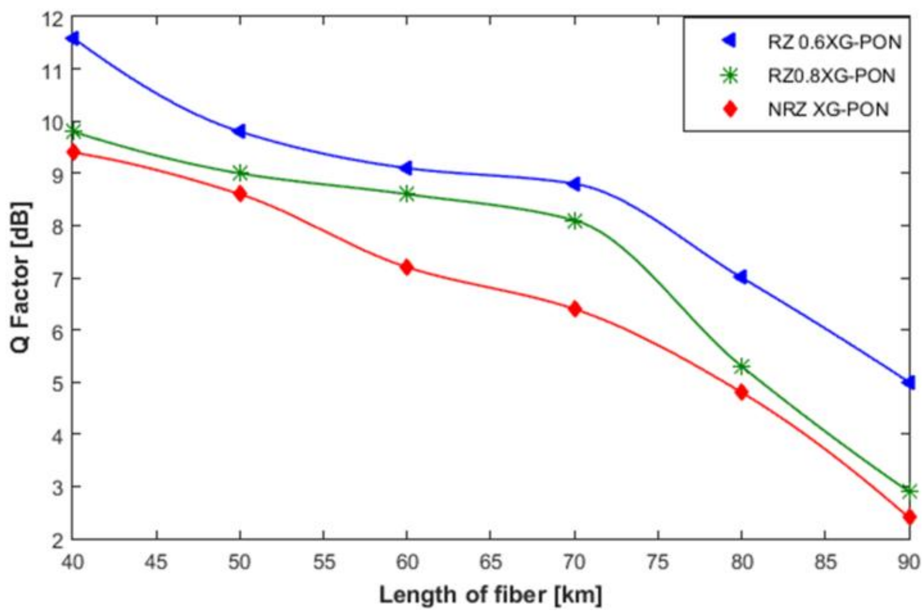


Figure 6 graphical depiction of the Q factor for the RZ and the NRZ downstream transmitted data for XGPON.

RZ modulation has come to be a widespread answer for the 10 Gb/s systems because of its smaller bit error rate, average peak power and a greater Signal to Noise Ratio (SNR) than NRZ modulation. It introduce better immunity to fiber nonlinearity and less liable to Inter Symbol Interference (ISI).RZ modulation typically accomplishes superior performing contrasted with NRZ.

The results of Q factor as a function of Length for NRZ as well as RZ with 0.6 and 0.8 duty cycle of GPON along with XGPON upstream signals are shown in figures (7, 8) correspondingly. Figure 7 shows the better option for upstream signals of the system is RZ data format. In 0.6 RZ of the GPON the transmission distance of the upstream signals can be carried out larger than 150 km and for XGPON the transmission distance of the upstream signals can be carried out up to100 km at BER of 10^{-9} and a minimum required of Q factor value which is (6.0 dB) as shown in figure (8).

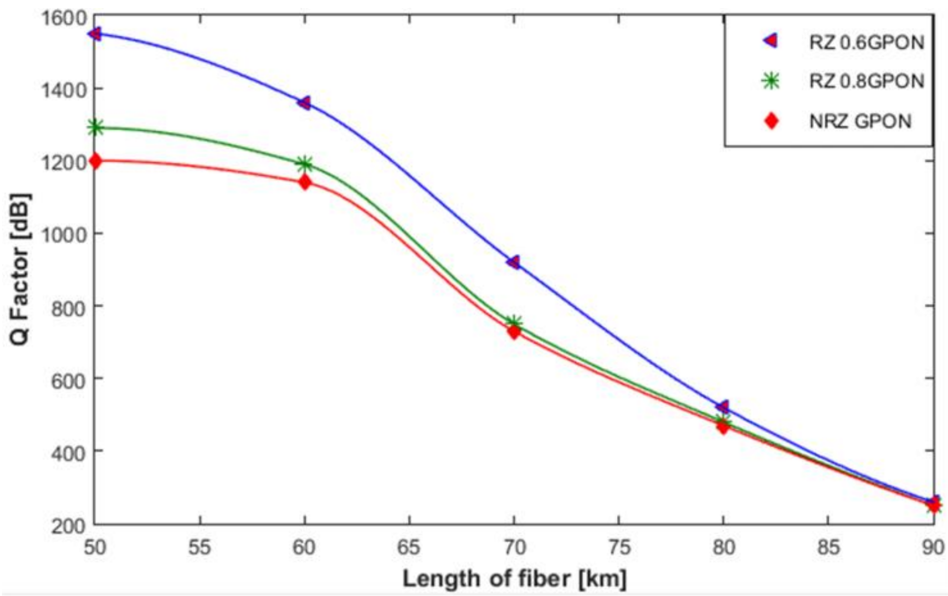


Figure 7 graphical depiction of the Q factor for the NRZ as well as the RZ upstream transmitted data for GPON.

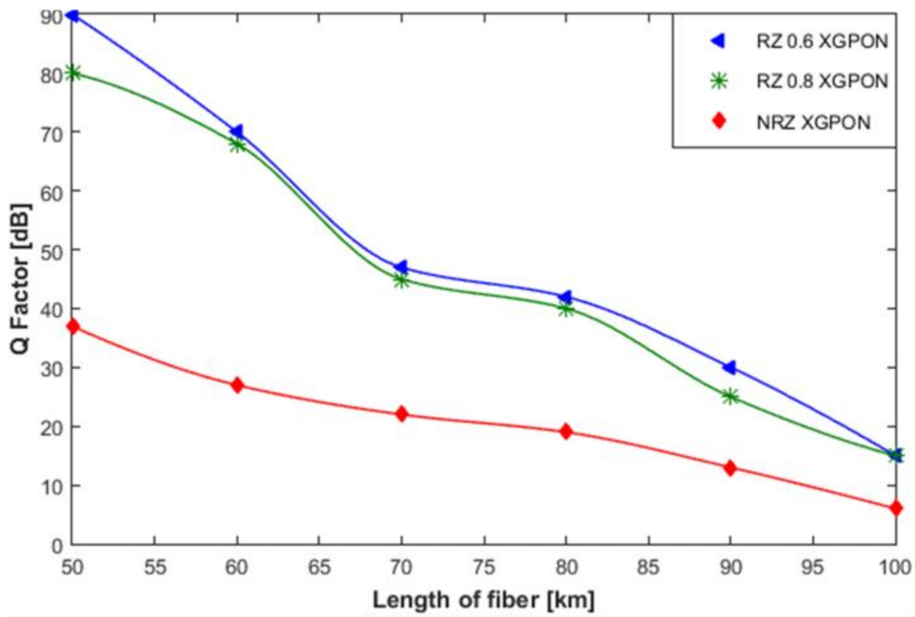


Figure 8 graphical depiction of the Q factor for the NRZ as well as the RZ upstream data transmission for XG-PON.

It has been chosen a single mode optical fiber which is commercially available as the reference fiber in order to understand the baseline performing. For 1550nm wavelength pumped signal by a laser source of 1450 nm a peak Raman gain with efficiency equal to 0.39 / (W·km) is used in the system fiber. The maximal Raman gain after gain scaling for the 1270nm signal has efficiency equal to 0.60/ (W·km) when it is pumped by source of 1206 nm. The attenuation loss of the system is 0.42 dB/km at 1206 nm and 0.32 dB/km at 1270 nm. Rayleigh backscattering coefficient at 1270 nm is $1.15 \times 10^{-4}\ km^{-1}$. By solving Equation (1) system baseline performance can be acquired using fiber parameters with no splices. Figure 9 shows the OSNR with respect to the pumping power which is rise and reach the maximum at 1150 mW due to effects of nonlinearity at high pump power. The optimal pump power as shown in figure 9 is nearly 920 mW with OSNR is 19 dB and resolution bandwidth of 0.1 nm.

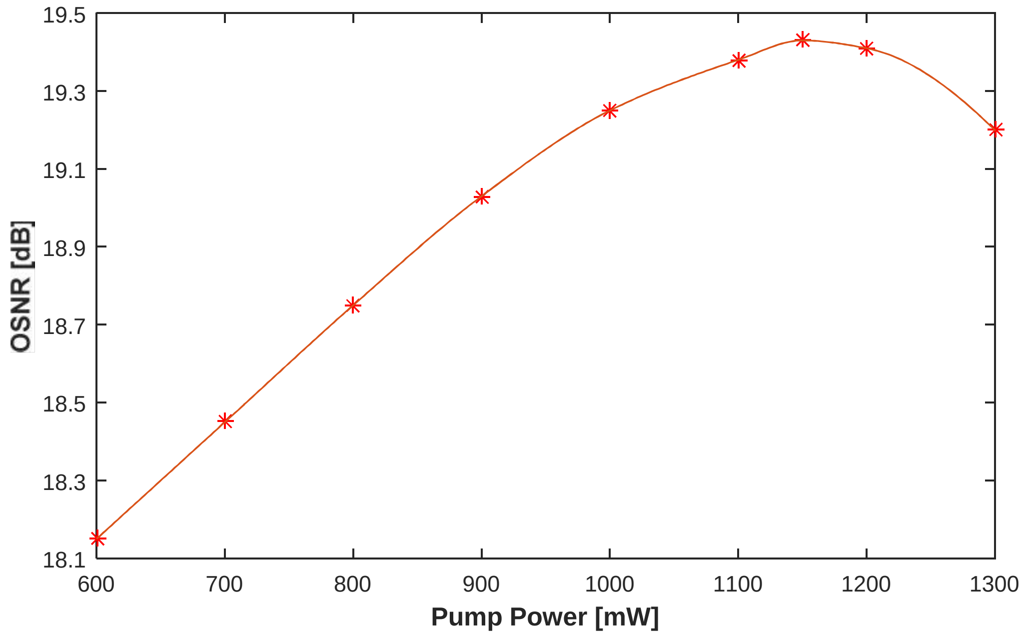


Figure 9 the OSNR with the pump power

Attenuation, back reflections and splice losses are added individually to the system and their performance is assessed for 1270 nm signal. The attenuation is increased in the first step by 0.01-0.03-0.05 dB/km for both signal and the pump in order to mimic the feasible environments of a lossier fiber. For 1270 nm signal the performance can be seen in Figure 10. Attenuation of 0.32 dB/km is included to fiber for comparison at 1270 nm.as shown in figure 10 the OSNR decline as fiber loss raising as a result additional pumping power is allowed for the system fiber. For 1270 nm the pump power increases for the reference fiber from 920 mW to 1010 mW for 0.35dB/km attenuation fiber. OSNR at 1270 nm are (18, 17, and 16) dB/0.1 nm for the attenuation of (0.33, 0.35 and 0.37) dB/km correspondingly.

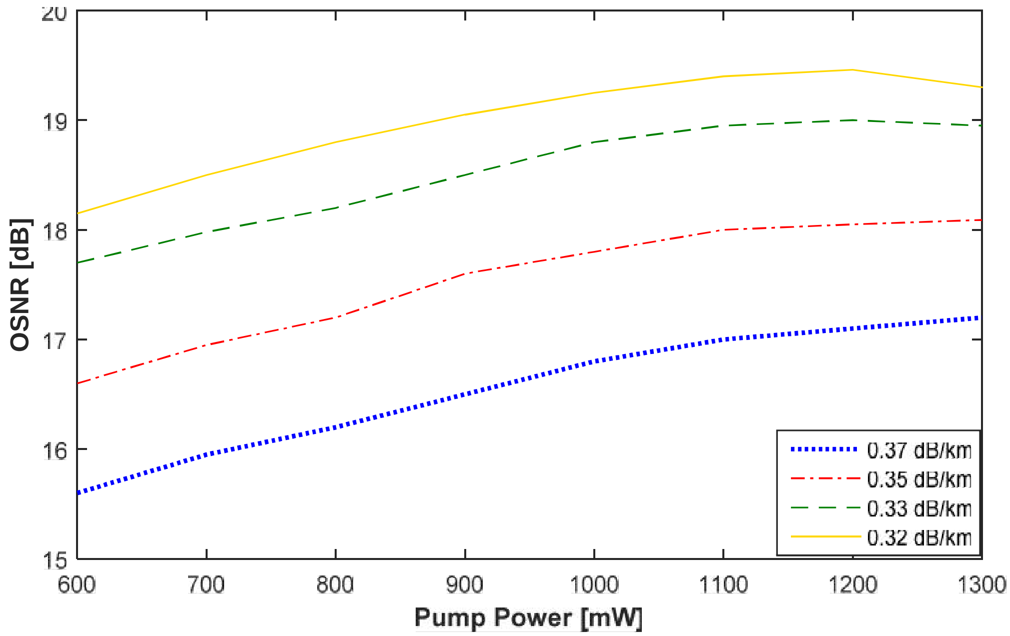


Figure 10 the OSNR with the pump power for different fiber losses.

The attenuation of 0.35dBkm is chosen for the system fiber at 1270nm and splice losses are introduced along the length of the fiber. Segments which has uniform length that varied from 1 - 5 km is assumed for consisting the 60 km the feeder optical fiber of the system. Figure 11 shows the OSNR as a function of the segment length for (0.01, 0.03, and 0.05 dB) splices losses. In order to achieve the greatest OSNR the pumping power is optimized. The pump power drops between 1000 - 1100 mW as depend on the splice loss. The OSNR as noticed decline rapidly with decreasing segment length or increasing the splices number. Explicitly, when the length of the segment is 2km the OSNR decline by (0.2 dB) with 0.01 dB increase of splice loss. The OSNR falls to 16 dB at each splice with 0.05 dB loss. The results show that it is serious to decline segments number of the fiber and managing the losses of splices.

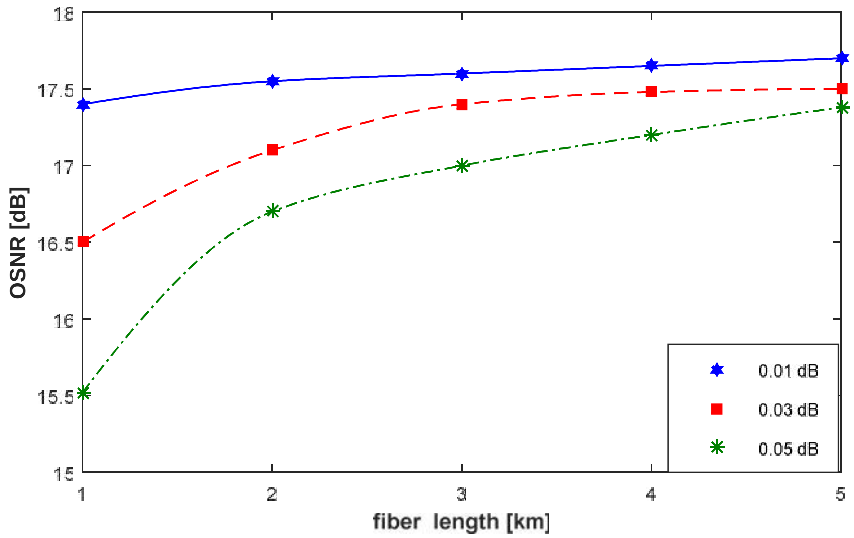


Figure 11 the OSNR with the pump power for different splice loss.

Lastly back reflections impact is examined for upstream signal of 1270 nm as shown in figure 12 with the following parameters: attenuation of (0.45dB/km at 1206 nm) and (0.35-dB/km at 1270 nm).the OSNR as a function of return loss is rises when back reflections have been considered.

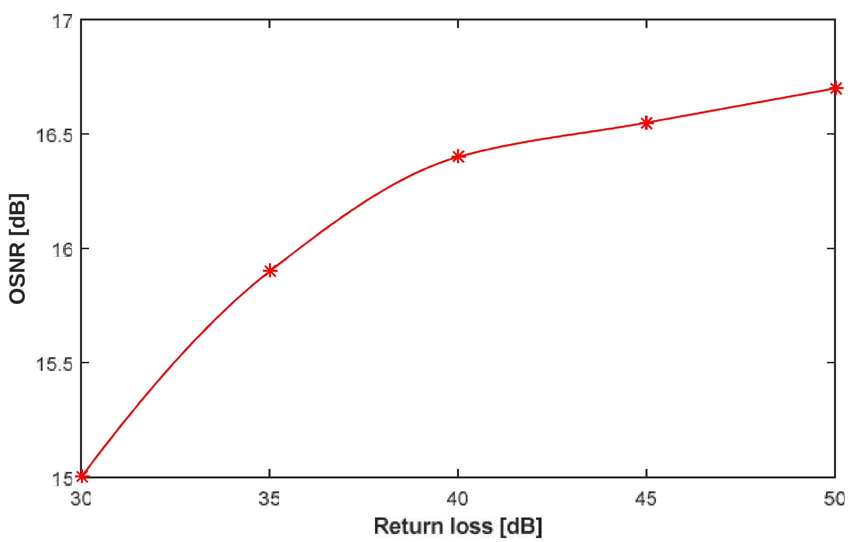
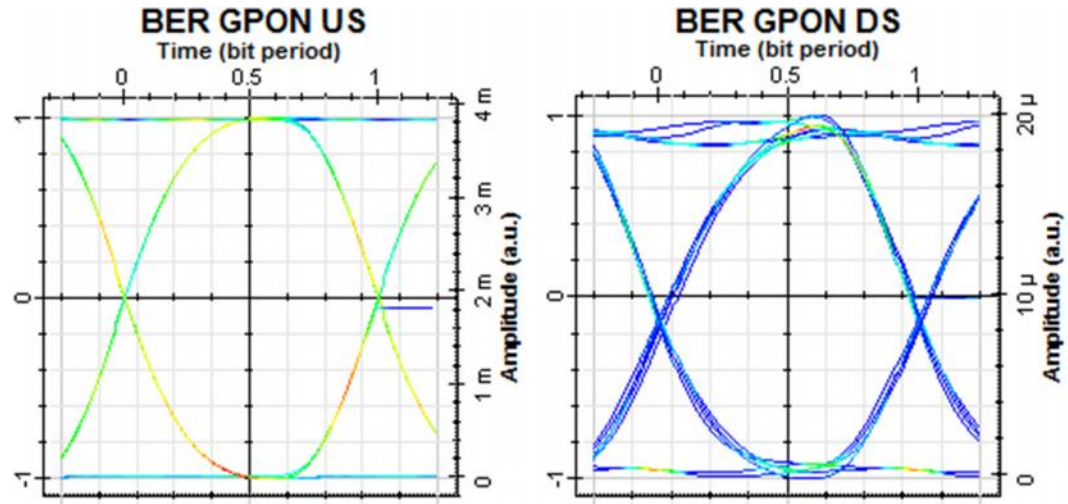


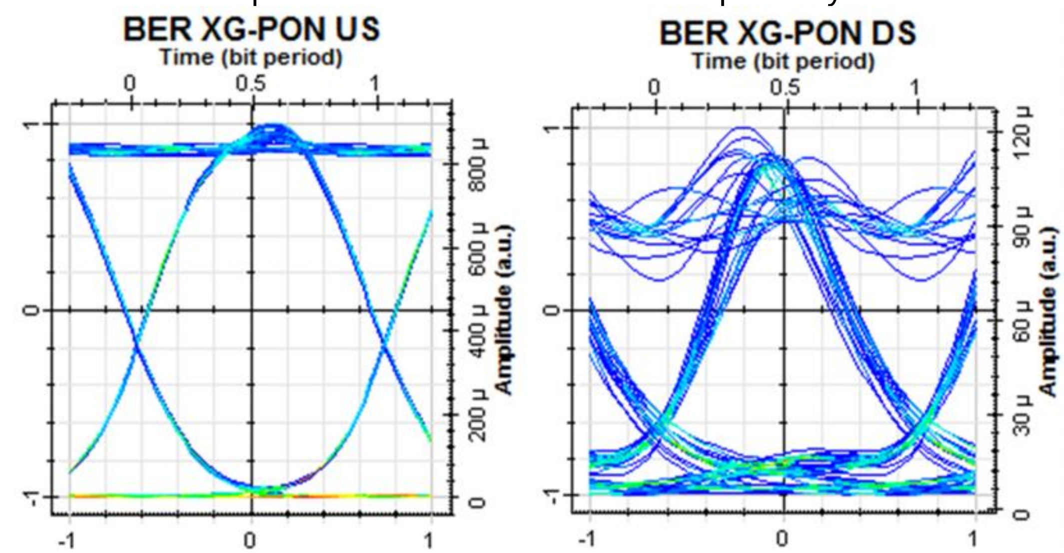
Figure 12 the OSNR for different values of return loss.

GPON and XGPON eye diagrams are shown in Figures (13, 14) for NRZ data format at 60 km of the upstream and the downstream respectively.



(a) **(b)**

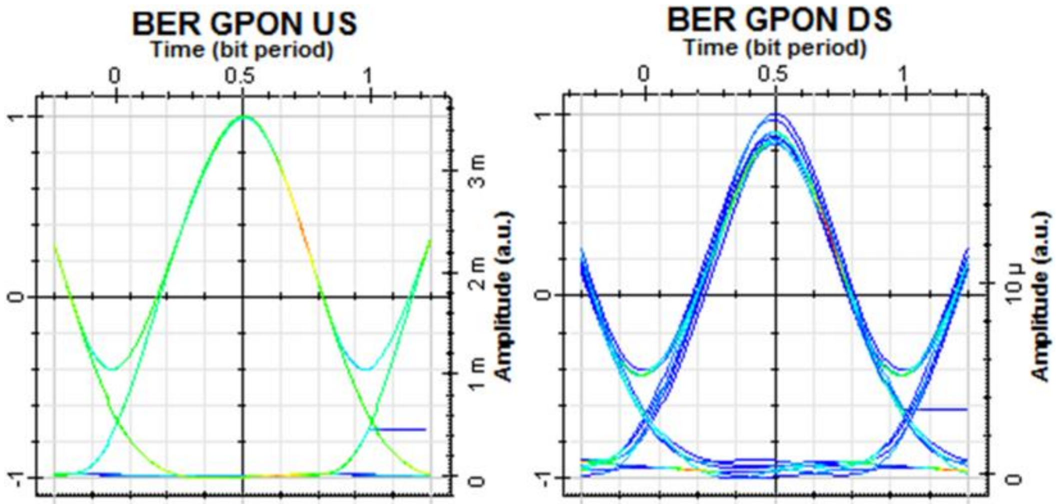
Fig 13 (a, b) eye diagrams for GPON in NRZ format at 60 km for the upstream and the downstream respectively**.**



(a) **(b)**

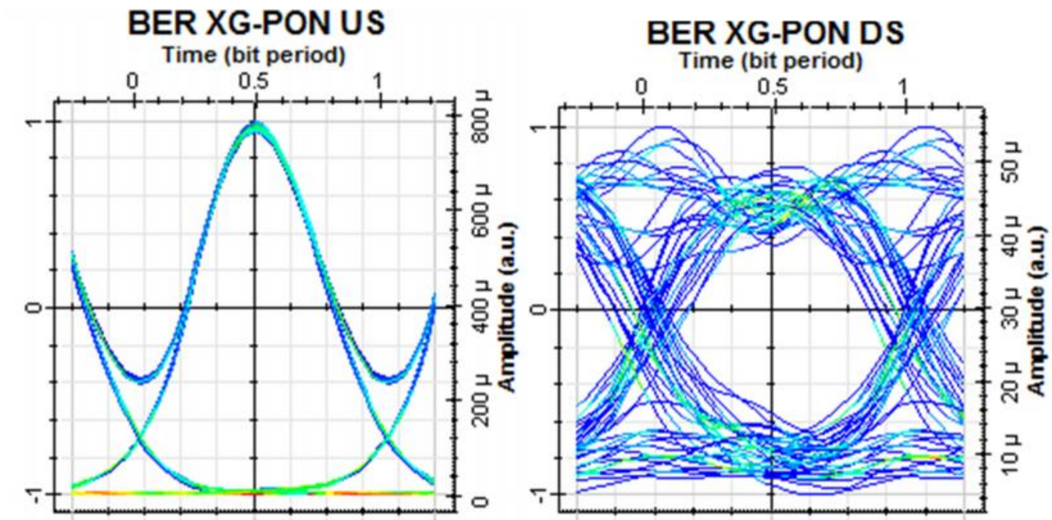
Fig 14 (a, b) eye diagrams for XGPON in NRZ format at 65 km for the upstream and the downstream respectively**.**

GPON and XGPON eye diagrams are shown in Figures (15, 16) for 0.6 RZ data format at 60 km of the upstream and the downstream respectively.



(a) **(b)**

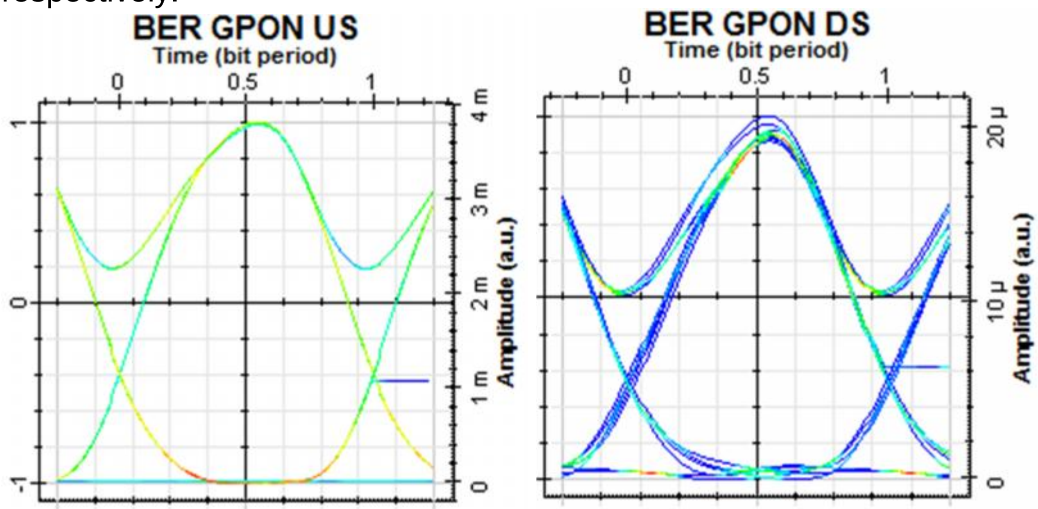
Fig 15(a, b) eye diagrams for GPON in 0.6 RZ data format at 60 km for the upstream and the downstream respectively**.**



(a) **(b)**

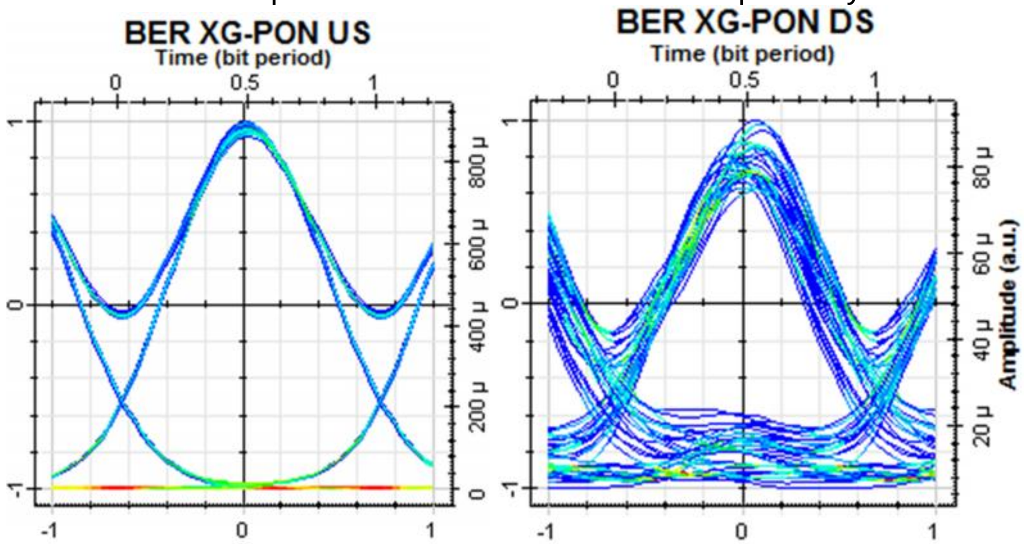
Fig 16(a, b) eye diagrams for XGPON in 0.6 RZ data format at 60 km for the upstream and the downstream respectively**.**

GPON and XGPON eye diagrams are shown in Figures (17, 18) for 0.8 RZ data format at 60 km of the upstream and the downstream respectively.



(a) (b)

Fig 17 (a, b) eye diagrams for GPON in 0.8 RZ data format at 60 km for the upstream and the downstream respectively.



(a) (b)

Fig 18 (a, b) eye diagrams for XGPON in 0.8 RZ data format at 60 km for the upstream and the downstream respectively.

7. Conclusion

Modern PONs deployment must be optimized by a number of concerns need to be considered for the network design which are the optimal using of the active equipment, cohabitation with the modern technologies and the flexibility to become easily adapted for future customer distribution and boosting operational budget because of the interventions of the field, these concerns will outcome in several design rules.

Based on results that attained by simulation of the coexistent system presented in this paper, the recommended value of the most significant parameters of system components were identified for achieving the optimal performance of these components.

The capability of RZ and NRZ formats signal communication of GPON and XGPON Raman amplification system has been evaluated on [40 - 90] km distance transmission. The results show that faithful transmission can be obtained farther than 65 km for the upstream and the downstream RZ signals of XGPON system. The RZ modulation format as compared with the NRZ modulation format of the coexisted system is superior due to its finer immunity to optical fiber nonlinearities. Furthermore, at higher bit rate the XGPON performance is declined because of the fiber nonlinearities effects.

As compared with the reference fiber, the OSNR for the Raman amplification of XGPON system reduced with the rising of optical fiber attenuation loss, splice return losses and splice losses which are assumed for practical optical communication systems. System performance evaluations is done particularly with parameters as follow 0.35 dB/km fiber attention, 0.05 dB splice loss and 40 dB return loss for each 2 km along the 60 km system fiber at 1270 nm. The resultant of link loss budget is also presented. It is proved that with this specifications as in real systems the suggested system is able to support 60-km logical reach and 64 ONUs.

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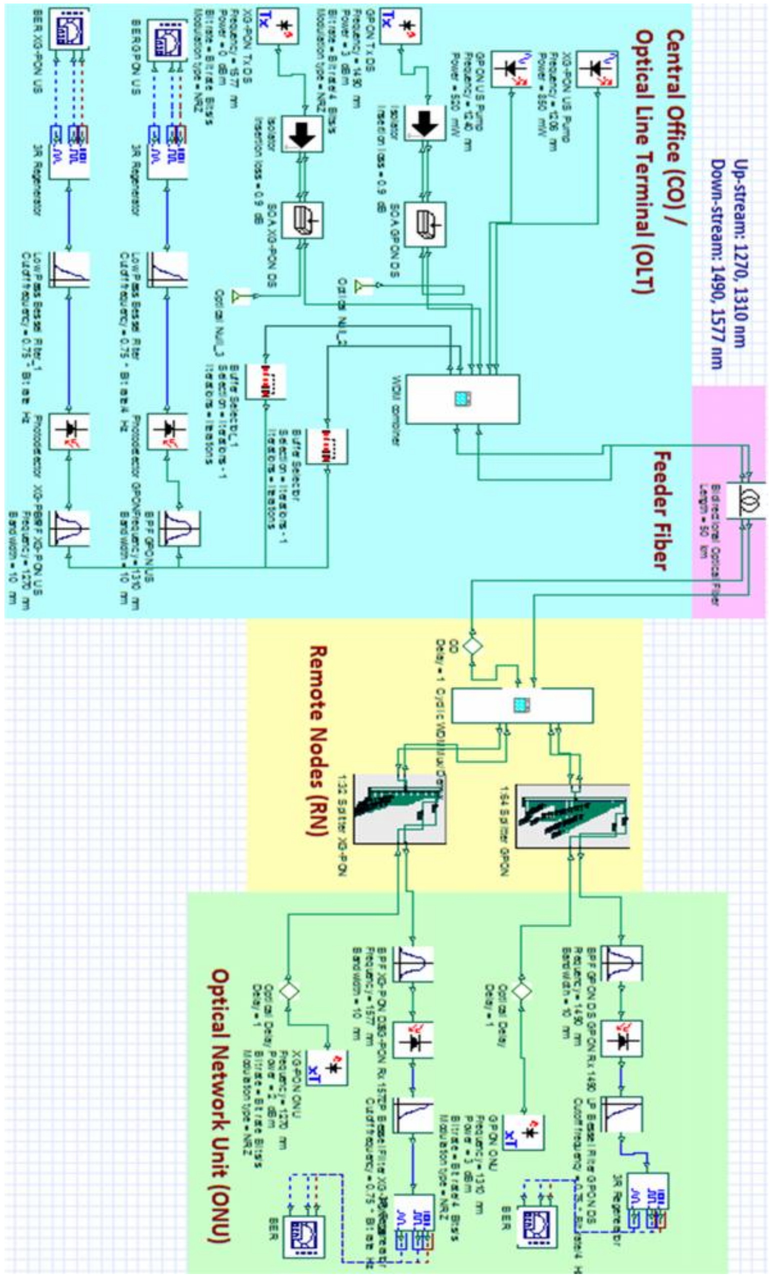
Appendix A

The Designed System using OPTISYSTEM Software



محاكاة التصميم لنظام XGPON المهجن ذو تضخيم رامان مع تنسيق البيانات من نوع NRZ و RZ

م.م مهند يوسف محسن*

المستخلص

يعتبر الجيل القادم من الشبكات الضوئية الخاملة الذي نضج بصورة ملحوظة في السنوات القليلة السابقة ويتوقع ان يتطور بصورة هائلة في المستقبل القريب ليصبح من افضل الشبكات الضوئية الواعدة. ضمن هذا التطور متطلبات القدرة ل NGPON سوف تتزايد وتصبح غير مرغوب بها. في هذا البحث تم توظيف نظام اتصالات ضوئي باستخدام تركيب مهجن من XGPON (WDM/ TDM) حيث في هذا النظام تم استخدام ليف ضوئي ثنائي الاتجاه لسيل البيانات المرفوع وسيل البيانات المحمل بتنسيق البيانات (0.6 و0.8 duty cycle) RZ و NRZ. وتم استخدام تضخيم رامان الموزع لسيل البيانات المرفوعة لتحسين الخسائر في XGPON. خصائص الاخماد وخسائر splice والانعكاسات الراجعة في نظام XGPON الواقعي اخذت هنا بعين الاعتبار. تم تحليل تاثير هذه المضعفات حسابيا على اشارة سيل البيانات المرفوعة ذات تضخيم رامان في نظام XGPON لطول موجي 1270 nm..

*الجامعة التكنولوجية