Performance Evaluation of Gigabit Passive Optical Networks with Fiber Raman Amplification

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Abstract— In this paper, performance of 2.5 Gbps Gigabit Passive Optical Network (GPON) employing Raman amplifiers is evaluated in terms of OSNR and Q factor with modulation formats such as return-to-zero (RZ), non-return-to-zero (NRZ), carrier-suppressed-return-to-zero (CSRZ) and duobinary-return-to-zero(DRZ).) Discrete or lumped Raman amplifier (LRA) is employed at optical line terminal (OLT) as booster for 1490 nm downstream whereas distributed Raman amplifier (DRA) amplifies 1310 nm upstream signal. The Q factor and OSNR performance metrics are observed by varying the input power and along the transmission fiber. The graphical results indicate that DRZ is better Q factor but its OSNR is less compared to other investigated formats. The Q factor for DRZ is 36.50 which is double than NRZ whereas former format shows around 14 dB better OSNR than the later. Moreover, investigations indicates that CSRZ and DRZ modulation formats GPON system range can be extended upto 350 km compared to RZ and NRZ.

Keywords—GPON, RZ, NRZ, CSRZ, DRZ, Q Factor, OSNR.

I. INTRODUCTION

The demand of cost effective optical access networks is recognized worldwide. To meet this requirement, passive optical networks (PONs) are generally employed. Nowadays, Gigabit passive optical networks (GPONs) are attractive area for researchers. To extend the reach of these networks optical amplifiers are widely employed. Additionally, it has been observed that, GPONs that employ Raman amplifiers can reach a distance of 60 km in comparison to the conventional passive access networks [1]. Moreover, to simplify the system, directly modulated DFB lasers can transmit the signals in these long reach extensions. According to design point of view, distributed Raman amplifiers can be used for both upstream and downstream with the pump wavelengths are to be selected very carefully [1].Similarly, a discrete Raman amplifier can also be used for downstream and distributed Raman amplifier can be used for upstream data [2].

Fiber Raman amplifiers (FRAs) are important component of high capacity optical transmission systems [3]. Multi pumped FRAs can be employed to improve the performance in terms of transmission gain bandwidth and gain flatness of the systems. It is shown that distributed FRAs (DFRAs) bandwidth can be increased from 45 to 97 nm and gain ripple decreases 0.82 to 0.47 dB by increasing one to seven counter propagating pumps [4]. A numerical design of DFRA propagation coupled equations is important for signal and pump evolutions along the transmission fiber. The design has obtained a minimum optimized gain ripple is 0.26 dB for 1 mW input signal powers with 50 km fiber length [5].

It is already found that, a Quantum dot pump laser at 1240 nm with 500 mW power can provide a Raman gain more than 15 dB to a 1310 nm upstream signal. More investigations point out, the pump power 850mW can result 18.9 dB maximum gain for 40 km standard single mode fiber [6]. L. Leng et. al. [7] have purposed GPON, employing Raman amplifier at central office (CO) to provide distributed gain in the 60 km feeder fiber extension and 1: 32 split ratio. The investigations revealed that effects of fiber attenuation, splice losses and back reflections due to splices restricts the distance reach to be 55 km (50 km feeder fiber and 5 km distribution fiber) with a split ratio of 1:32 only [7].

S. Verma et. al. [8, 9] have reported Q factor 9.18 by compensating the dispersion with fiber Bragg grating fiber (FBG) for a length 20 km in GPON with controlled polarization effect. Moreover, in another set up they obtained Q factor 13.9572 by employing user defined bit sequence generator with uniform FBG for dispersion compensation for fiber length 70 km when polarization is not taken into account [9]. A Kaur et. al. [10] have compared different modulation formats of GPON and XGPON with semiconductor optical amplifier (SOA) for downstream and distributed Raman amplification for upstream transmissions. They have shown that, RZ data format provides 27.48 higher Q-factor, compared to NRZ, due to the non linear effects in bidirectional optical fiber 50 km [10].

J. P. Turkiewicz et. al. [6] have indicated that SOA in GPON results strong signal distortions like noise and saturation effects whereas the Raman amplifiers offer a low noise figure and high saturation output powers [6]. The implementations of advanced modulation formats like CSRZ, DRZ and MDRZ in GPON results in fiber distance reach of 250 km for variations of data rates in a range of 2 to 2.5 Gbps. Moreover, it has been reported that, Q factors 44.3828, 60.3497 and 117.112 for CSRZ, DRZ and MDRZ respectively are obtained for a distance of 240 km [11].

The preceding exhaustive literature review indicates there is a big scope of advanced modulation formats and fiber Raman amplifier for performance improvement of GPONs. Additionally, a distributive fiber Raman amplifier needs no extra devices except a coupler to launch a suitable Raman pump/multiple pump waves in access fibers.

In this paper a gigabit passive optical network employing fiber Raman amplifiers along with conventional and advanced modulation formats upstream and downstream are investigated. After this introduction in section 1, the paper is organized as follows: section 2 elaborates the system set up and different values of parameters selected, section 3 contains the results obtained and performance evaluations are discussed in it. Section 4 conclusions are drawn and future scope of the work is discussed.

II. SIMULATION SETUP

A purely 2.5 Gbps passive GPON system set up shown in fig. 1 is designed such that, a central office (CO) working as optical line terminal (OLT) contains discrete fiber Raman amplifier for downstream and a CW pump laser to amplify upstream signals. The OLT is connected by feeder fiber to Remote node (RN). To Feeder fiber is a type of AllWave fiber for zero water peak attenuation and its length varied in a range of 60 to 350 km. The RN having splitting ratio 1: 128 is connected to various optical network units (ONUs). The very simple and cost effective ONUs are installed at subscriber premises. A 1400 nm pump wave at 100 mW power is employed to pump discrete fiber Raman booster to amplify the downstream transmission. Similarly, for backward pumping a power pump wave of 1240 nm at 950 mW is employed at OLT, for distributed Raman amplification of upstream signal. The transmitter section consists of a pseudo-random bit sequence generator (PRBS) generator, RZ NRZ pulse generator, a CW laser as light source and a Mach-Zehnder modulator (MZM). For CSRZ and DRZ modulation formats transmitter schematic diagrams are indicated in fig. 2(a) and (b) respectively. These are special format generated by employing various transmitter components such as $LiNbO_3$ modulators, sine generators, delay elements and filters.

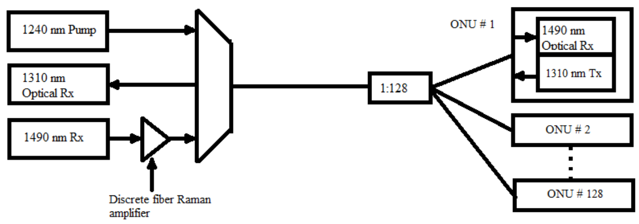
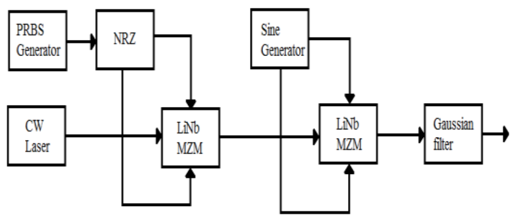
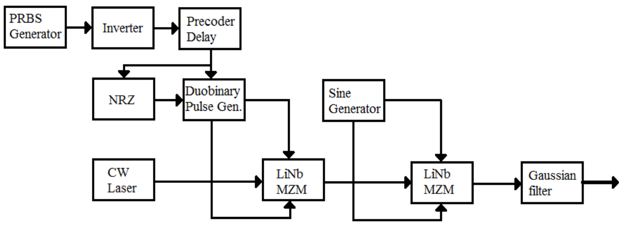


Fig. 1 GPON system setup employing fiber Raman amplifiers



(a)



(b)

Fig. 2 (a) CSRZ transmitter (b) DRZ transmitter

Table 1 (a) Upstream and Downstream Signal Transmission Parameters

S.No.	Parameter	Downstream	Upstream
1.	Wavelength (nm)	1490	1310
2.	Bit rate (Gbps)	2.5	2.5
3.	Fiber attenuation (dB/km)	0.21	0.32
4.	Effective core area (μm^2)	80	66

Table 1 (b) Fiber Raman amplifier's Pumping Parameters

S.No.	Parameter	Discrete Fiber Raman amplifier	Distributed Fiber Raman amplifier
1.	Pump wavelength (nm)	1400	1240
2.	Pump power (mW)	100	950
3.	Peak Raman gain Coefficient g_R (m/W)	3.93×10^{-13}	1×10^{-13}
4.	Effective fiber core area A_{eff} (μm^2)	25	66
5.	Rayleigh back Scattering Coefficient (km^{-1})	5×10^{-5}	5×10^{-5}
6.	Attenuation (dB/km)	0.6	0.32
7.	Dispersion (ps/nm/km)	-100	16.75

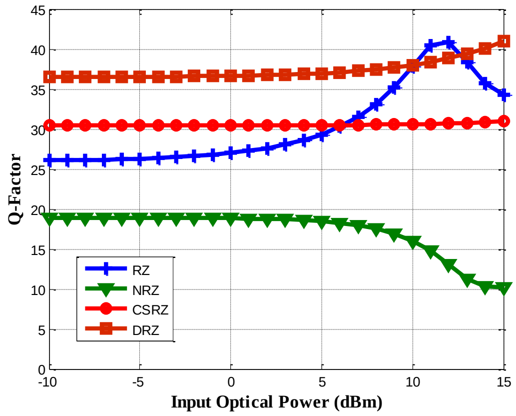
Table 1(a) shows the downstream and upstream transmission parameters selected for the system. Table 1(b) shows the parameters selected for discrete and distributed fiber Raman amplifiers.

III. RESULTS AND DISCUSSIONS

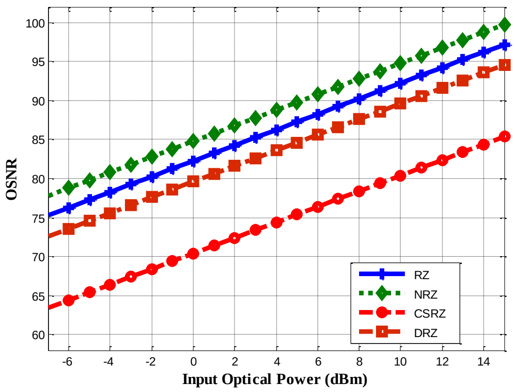
The performance of GPON range extension is evaluated by varying fiber length and input optical power launched in the fiber. The set up is investigated for modulation formats such as RZ, NRZ, CSRZ and DRZ for upstream as well as downstream transmissions. Firstly, for downstream, input optical power launched in the fiber is changed in a range -10 to +15 dBm and corresponding effect on Q factor at ONU # 1 are observed. Moreover, for realistic scenario we have taken two cases of feeder fiber length for modulation formats. In case 1, fiber length is set at 60 km for RZ and NRZ, whereas for case 2, it is 250 km for DRZ and CSRZ.

Fig 2 (a) indicates plot of Q factor with input power for RZ, NRZ, CSRZ and DRZ formats. It is evident that DRZ shows better Q factor compare to other formats in the investigated input optical power range. Clearly, at -10 dBm input power, it is 26.08, 18.88, 30.42 and 36.50 for RZ, NRZ, CSRZ and DRZ respectively. NRZ format results a continuously degrading Q factor with minimum value of 10.23 at +15 dBm power due to the Raman ASE and double Rayleigh back scattering (DRBS) noise. Whereas, with RZ, Q factor improves upto +12 dBm power and starts degrading continuously.

Fig 2 (b) shows the plot for OSNR varying input optical power at for different modulation formats. The OSNR increases linearly with respect to the launched power for all the formats. The maximum OSNR values obtained are 99.73, 97.18, 94.58 and 85.39 for NRZ, RZ, DRZ and CSRZ respectively at 15 dBm power. CSRZ shows the most degraded performance and about 15 dB difference with NRZ format.

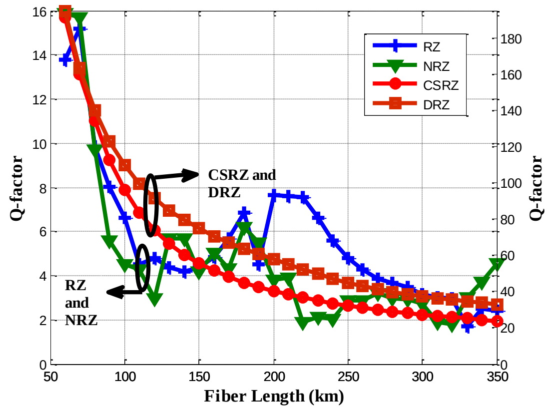


(a)

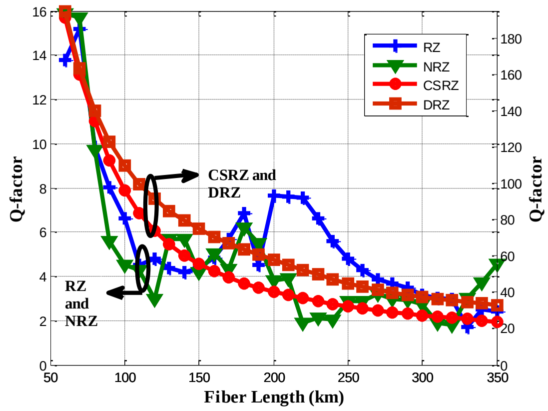


(b)

Fig. 2. Downstream signal at wavelength 1490 nm, (a) input power (dBm) versus Q-factor (b) input power (dBm) versus OSNR (dB).



(a)



(b)

Fig. 3. (a) Downstream signal at 1490 nm wavelength, Fiber Length (km) Versus Q-factor (b) Upstream signal at 1310 nm wavelength, Fiber Length (km) Versus Q-factor.

Fig 3(a) shows the results for Q factor by varying the length of the fiber from 60 to 350 km and keeping the input power at 20 dBm for 1490 nm downstream signal. At 60 km the Q factor is 13.79 and 15.89 for RZ and NRZ respectively. For CSRZ and DRZ the Q factor is 32.21 and 45 respectively at 250 km fiber length. For DRZ and CSRZ the Q factor decreases exponentially with respect to the length of the fiber. But for RZ and NRZ the Q factor decreases and again increases due to Raman ASE and DRBS noise effects. RZ has a rise in the Q factor giving a value of 7.51 at 190 km and again starts decreasing continuously after 220 km but for NRZ the Q factor show a number of ups and downs with respect to length of the fiber. Here the point to be noticed is that NRZ gives a sufficient Q factor value up to 80 km only and decreases afterwards. RZ has range extended up to 100 km whereas CSRZ and DRZ can reach about 350 km. At 350 km the Q factor values are 2.42, 4.57, 23.85 and 32.75 for RZ, NRZ, CSRZ and DRZ respectively. These are sufficient with CSRZ and DRZ for successful optical transmission link but highly degraded for RZ and NRZ.

Fig 3(b) shows the results of Q factor versus varying transmission AllWave fiber length for 1310 nm upstream signal. At 60 km fiber length the Q factor is 13.29 and 15.87 for RZ and NRZ respectively. For CSRZ and DRZ the Q factor values are 24.76 and 26.72 respectively at 250 km fiber length. For RZ the Q factor value decreases at 160 km and starts increasing again at 240 km whereas for NRZ the Q factor value is continuously decreasing. The rise in the value of Q factor at 240 km is due to the presence Raman ASE noise and DRBS noise effects with RZ. CSRZ and DRZ the value of Q factor is continuously decreasing at higher distances. NRZ and RZ can provide an extended range of 100 km with a Q factor of 5.48 and 11.99 respectively. The Q factor values of 17.41 and 19.02 are obtained at 350 km for CSRZ and DRZ respectively.

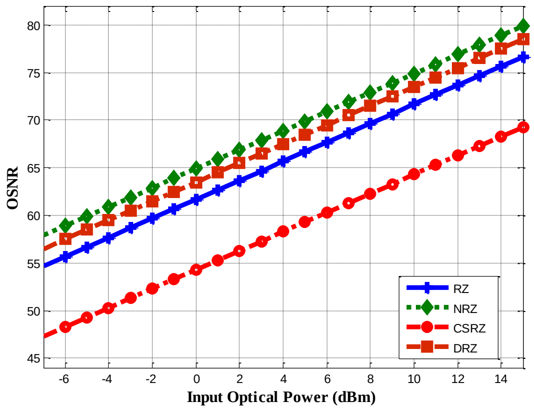


Fig. 4 Upstream signal at 1310 nm wavelength, input power (dBm) Versus OSNR (dB)

For 1310 nm upstream signal OSNR at different input power values at 60 km is investigated as shown in Fig 4. The maximum value obtained is 79.88 for NRZ format. The DRZ format shows nearly the same results as NRZ. CSRZ gives the maximum value of OSNR as 69.28 which is about 10 dB less than the NRZ format.

Table 2, shows the comparison of the conventional systems with the proposed GPON system. Discrete Raman amplification can provide extended range of 80 km for RZ and NRZ as compared to reference [1 & 2] that can reach only 60 km. CSRZ and DRZ have the range extended up to 350 km as compared to reference [11] in which range is extended up to of 255 km only. For CSRZ and DRZ the Q factor obtained for proposed system is 31.04 and 42.97 as compared to 9.45 and 4.81 for the reference [11]. These comparisons of GPON transmission fiber range and Q factor indicates with advanced modulation formats indicates beneficial for fiber to the home (FTTH) communication scenario

Table 2 Comparison of proposed system with referred work

S. N.	Parameter	Ref. [1]	Ref. [2]	Ref. [11]	Proposed System
1	Input Power (dBm)	3	10	20	-10 to +20
2	Fiber Length (km)	60	60	240-255	100 (RZ and NRZ), 350 (CSRZ and DRZ)
3	Q factor	None	None	44.38t o 9.45 (CSRZ), 60.34 to 4.81 (DRZ).	15.17 to 2.42 (RZ), 15.89 to 4.57 (NRZ), 191.32 to 23.85 (CSRZ), 194.67 to 32.75 (DRZ).
4	Type of amplifier	DRA for upstream and Down stream	LRA for downstream and DRA for upstream	None	LRA for downstream and DRA for upstream
5	Modulation Format	NRZ	NRZ	CSRZ, DRZ and MDRZ	RZ, NRZ, CSRZ and DRZ

IV. CONCLUSION

The performance investigations of GPON system with fiber Raman amplifiers using advanced modulation formats i.e. DRZ and CSRZ show better results in terms of Q factor compare to RZ and NRZ but these formats are also affected by the noise generated with amplification. Conventional formats RZ and NRZ show better results in terms of OSNR but fiber length range of GPON with these formats is only up to 80 km. Further, CSRZ format maximum OSNR obtained is 99.73 for NRZ for downstream and 79.88 for upstream whereas the minimum value of OSNR is 85.39 for downstream and 69.28 for upstream. The use of Raman amplifiers along with the advanced modulation formats such as CSRZ and DRZ enables the reach extended up to 350 km with a Q factor value of 23.85 and 32.75 respectively whereas the conventional formats i.e. RZ and NRZ can provide the reach extended up to 80 km with Q factor values of 9.86 and 9.68 respectively. It is evidentially, can be seen that the proposed system is comparatively better in to extend the range with Q factor.

Moreover effect of noise generated with Raman amplification in the proposed GPON system can be analyzed as future scope of this work.

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ACKNOWLEDGEMENT

I am thankful to my guide Dr. Kulwinder Singh for his continuous guidance and valuable suggestions. I am also grateful to my parents for their moral support.

Arvinder Kaur is an M.Tech scholar in Punjabi University, Patiala. Her areas of research are GPON networks using Raman amplifiers and Advanced modulation formats.