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Downstream Performance Analysis and Optimization of 2.5 Gbit/sec GPON-FTTX using NRZ and RZ Modulation Formats

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Abstract: In this study, a system consist of optic fiber communication downstream analysis has been utilized by employing co-existing GPON-FTTX architecture. In this system by changing the input power and the length of the fiber, gave us ability to analysis and execute this design performance by inspecting the two type of data formats Return-to-Zero (RZ) and non-return-to-zero working at constant bit rates 2.5 G. The simulative analysis has shown how outstanding the RZ modulation format as compare to the traditional NRZ modulation design due to preferable inviolability to average peak power and non-linearities fiber, it is also evident from the results that RZ can reach up to 90 km with 5 dB power and with any wavelength (1557 or 1490 nm) and beyond which BER is above 10^{-9} (bad signal) in contrast the NRZ with power 5 dB has reach 40 km with 1557 nm and 70 km with 1490 nm.

Key words: GPON, FTTX, NRZ, RZ, inspecting, modulation, wavelength

INTRODUCTION

Increasing request of bandwidth because of the fast development of three-dimensional HD TV and cloud computing makes modern defy to bandwidth deployment and running (Kaur *et al*., 2013; Verma *et al*., 2016). Nearly all of metro network runner came with the realty of the challenge that how to design a regular backing to multiple client networks and over raise traffic's transmission capacity (Zhang *et al*., 2014). So by trying to address this picture, Passive Optical Networks (PON) technologies was proposed, the tendency of PON development is a big matter for the company and telecommunication manufacturer. As the bandwidth request are ever rising by the user's (Kaur *et al*., 2013).

Passive Optical Network (PON) is mostly count as the widely hopeful optical access network settling considering its high-speed broadband services to individual and enterprise users and cost effectiveness (Kachhatiya and Prince, 2018). But employing passive components doesn't mean, we connect each subscriber with an individual line to the CO (Central Office) as shown in Fig. 1a this will be waste of resources and power in state of that we want to minimize the power, cost and repair, so, we come up with point to multi point transport network as shown in Fig. 1b (Rajalakshmil *et al*., 2012). PON were obtainable, since, 1995, lately criterion have become round and merchant standard are achieved, first, PON was (APON) short cut for ATM PON then they develop name (BPON) short cut for Broadband PON. BPON to be successful they make it convenient with APON. Gigabit PON (GPON) is an alternative solution now in our days for PON networks (Lin *et al*., 2017).

The exponential development of universal communications these day's request next generation PON that has big data rates and huge spectral qualification. presently extreme prevail PONs are gigabit Passive Optical Network (GPON) (Prat *et al*., 2014). GPON (Gigabit Passive Optical Network) has increase ability in the contrast with APON and BPON. It is known by ITU-T reference series G.984.1 through G.984.4 which define general characteristics.

This being also, the more stringent in specifications than IEEE 802.3ah EPON and scaled to XGPON1 (Hazra *et al*., 2013). The GPON criterion diverge with other PON criterion in which it obtains bigger efficiency, smaller in size as shown in Fig. 2 and bigger bandwidth employing bigger, changeable length packets. GPON

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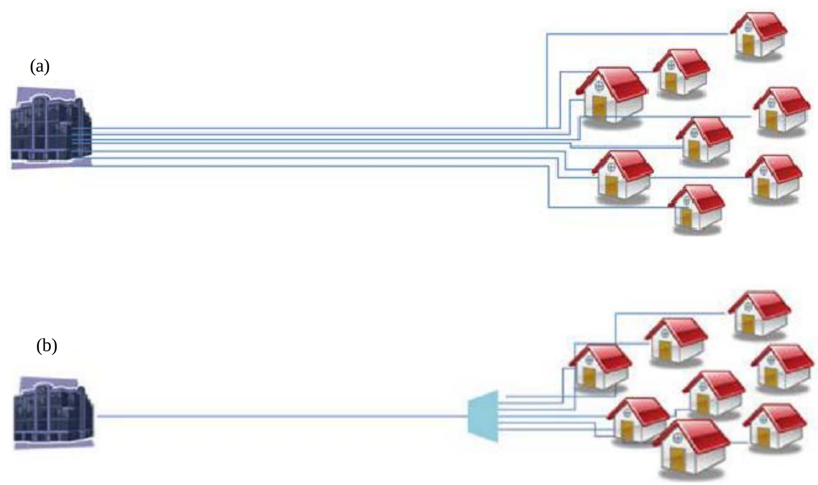

Fig. 1: Passive optical network: a) point-to-point fiber and b) Point to multipoint network (Alameen, 2017)

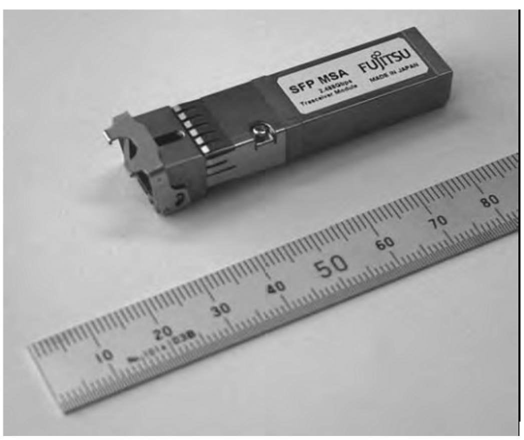

Fig. 2: Gigabit Passive Optical Network (GPON) transceiver, shows how small are the GPON equipment (Bakarman *et al*., 2010)

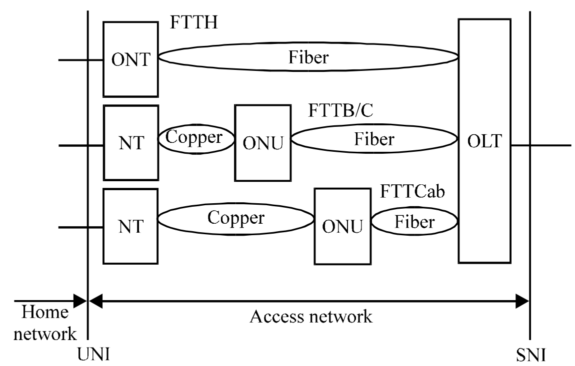

Fig. 3: FTTx network architecture explain FTTX connection between OLT and ONT and how the fiber are represent compared to the entire network (Coomonte *et al*., 2013)

shows effective user traffic packaging with framework division permit bigger Quality of Service (QoS) for video communications transit and postponements sensitive voice (Senior and Jamro, 2009).

Superiority goes back to his perfect tolerance in chromatic dispersion, high spectral effectiveness, distribute the bandwidth dynamically and pliable farther more this advantage goes to the frequency capacity of the adjust channel that attached kindly with easy single tap equalization (Prat *et al*., 2014). So, we select Full-Services Access Networks (FSAN) GPON to supply high bandwidth services to customers depending on a various Fiber-To-The premises/cabinet/building/home/user (FTTx) story (Lu *et al*., 2015). Noway, Passive Optical Networks (PONs) are considered as a promising solution for Fiber To The X (FTTX) and widely deployed (Cheng *et al*., 2008). Gigabit Passive Optical Network (GPON) is counted as a so, favourable technique to execute FTTX system (Prat *et al*., 2014).

As shown in Fig. 3, Fiber To The Home (FTTH) will be the target of most transporter instead of (FTTC, FTTB) all over the world (especially, North America and Europe) because of the fiber with his big advantage that represent most of the network transporting line, so, he becoming the extreme interesting, clean technology utilized in FTTH implementation. Rather than, the copper and his problem (especially, electromagnetic influence). New technology has been expanded for the FTTH implementation (Cale *et al*., 2007; Verma *et al*., 2016). FTTX technology employ optical fibre to link subscribers at their building with two-way transmission velocity of more than 100 Mbps. Going ahead with progress in fibre-optic gear are centre on growing these velocities without substitute the prevailed fibre, making a “futurity proof” next generation network technology (Stankiewicz and Jajszczyk, 2011). Broadband access is also needed in fixed networks. A range of FTTx technologies will play a growing role in this area (Conti *et al*., 2011). In summary, FTTH/B networks are counterweight to become the next main success scenario of optical networking technologies, however, GPONs will play a main key across their evolutionary improve to NG-PONs by benefit on a number of newly authorise technologies, e.g., OCDM and OFDM (Gilfedder, 2006).

MATERIALS AND METHODS

It has been known that PON architectures can be fiber effective matched with point-to-point approach and that the advantage rises as node intensity turn into very high. This mention that high capacity, mean rising the split long-reach PONs and that s could be very fiber effective in the long period. With consideration to real network script and traditional backhaul technologies it has been known that GPON, although, not the cheapest solution at this period does note further benefit and examination, especially as component costs reducing through time and with raised volumes. GPON-FTTX consist as all PON network from three divisions, illustrate the OLT (Optical Line Terminal) research as transmitter, ODN (Optical Distribute Network) and ONT (Optical Network Terminal) research as receiver as shown in Fig. 4.

Designing GPON systems is a hard job in that a number of tough rules should be involve to, however, at the same time trying to reduce equipment and fibre use. When the matter of protection is involved and a common deployment strategy is counted, publication design of GPON systems may become unwieldy and some process of automated design will be vital (Yin *et al*., 2009).

The main key for understand the system task is chosen of system analysis and type of the fiber implementation. In the top of the list of downlink receiver particularly are the characteristic budget and parameter regulation. But as we see in the test of by pulse widening and waveguide dispersion, the receiver power penalty may minimize the impact on Bit Error Rate (BER) and receiver sensitivity (Kachhatiya and Prince, 2018).

The testing of the optical system’s demand depending on a bandwidth about 2.5 Gbps, that carry a big criterion. So, we employ Return-to Zero (RZ) and Non-Return-to Zero (NRZ) data format in the design that has velocity are under 10 Gbps (Kachhatiya and Prince, 2018). The link should carry about 2.5 Gbps RZ and NRZ

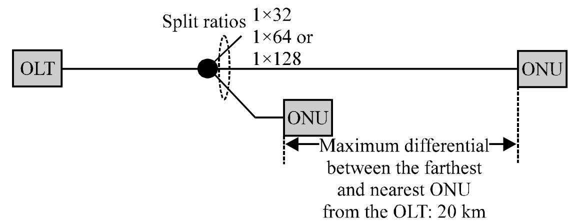

Fig. 4: Gigabit Passive Optical Network (GPON) shows the three main section in any PON the OLT which represent the source, ODN which represent the splitter with the fiber (range from 20-90) and ONU which represent the destination (Bakarman *et al*., 2010)

input string, over a 90 km path with BER of 10^{-9} or smaller. This should be done without amplifier or repeaters the test forward will point out to what scope these forecasting is right. Calculation of BER, type of modulation (RZ, NRZ), Q-factor, power budgets and distance explain the size of the analyses. We used in our design simulation an optisystem software program depending on the optical transceiver standard and pattern of GPON transmission link (Vukovic *et al*., 2007).

Simulation: This part explains the simulation setup in OptiSystem where all vital parameters established on the GPON. Figure 5 shows the schematic downstream transmission of two user GPON system. We will focus on the receiver side (Mrakovic and Matavulj, 2011). The Fig. 5 is the scheme The test on the GPON optical transmission system in a standard event fundamentally includes. OLT transmitter is act as a RZ and NRZ signal sender, PRBS (Pseudo-Random Bit Sequence) with represent the shape of what is known with 2.5 Gb/sec bit rate data signal (Mrakovic and Matavulj, 2011). The scheme of the GPON-FTTX includes (ITU., 2003).

OLT: Optical line terminal represent the transmission side as shown in Fig. 5 the main details shown in Fig. 6.

PRBS (Pseudo-Random Bit Sequence): That was design to generate 2.5Gbps, that is the downstream data rate of GPON. The data coded via. (NRZ Non-Return-to Zero, RZ Return-to Zero) as shown in Fig. 6a, b, respectively.

CW (Continuous Wave): Is a laser work as a modulation carrier signal wavelength of light that use to generates two light sources with 1557 and 1490 nm. We use power =-5, -3,0, 3, 5 dBm in RZ and NRZ modulation format at 1490 and 1577 nm for downstream sender with constant rate 2.5 Gb/sec. downstream window is only 10 nm wide.

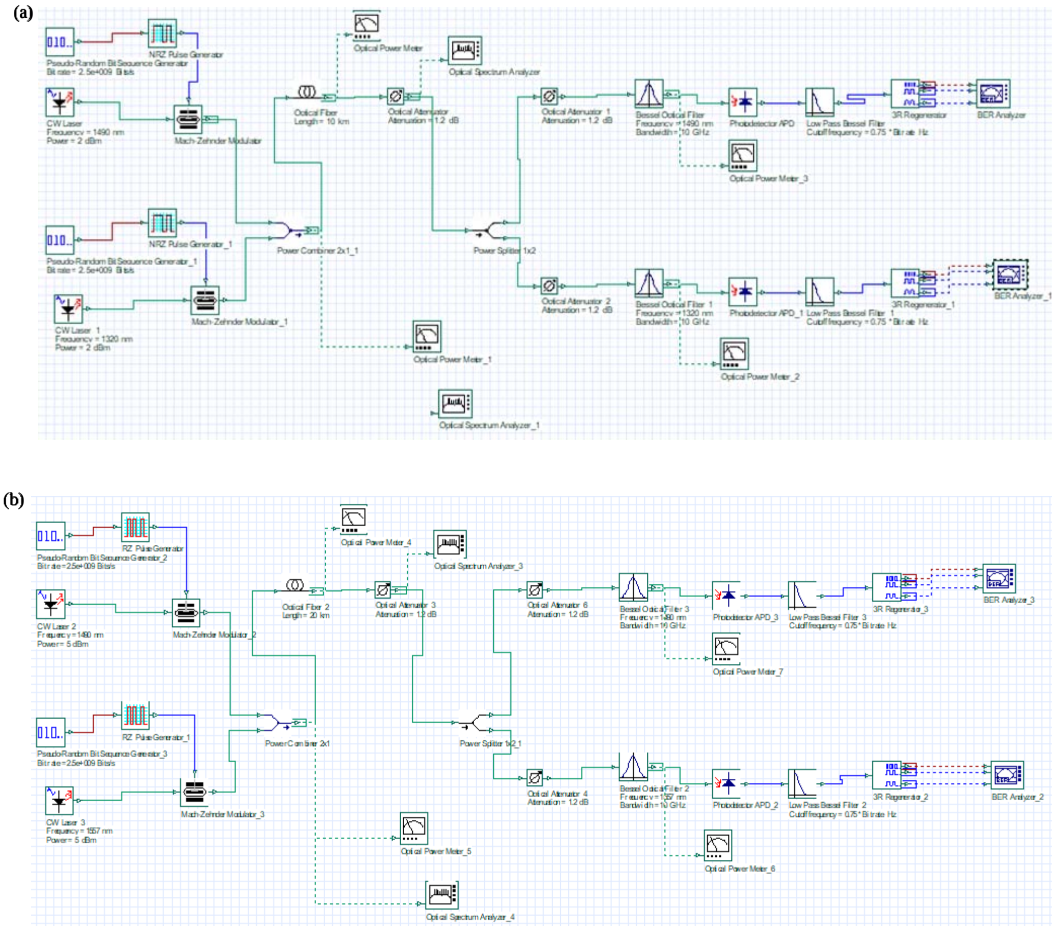

Fig. 5: Schematic downstream transmission of two user GPON-FTTx system: a) using NRZ modulation format and b) RZ modulation format

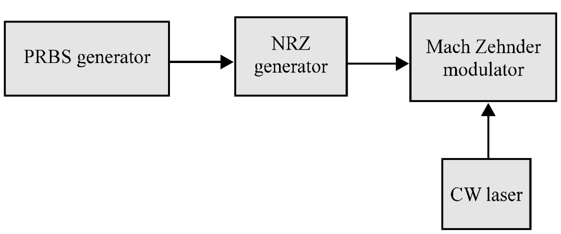

Fig. 6: Transmitter component of GPON (Alameen, 2017)

MZM (Mach-Zehnder Modulator): Works at operating wavelength of GPON to prepare the electrical signal for transporting through the fiber. MZM has three gates, the first gate for electrical modulation kind, the 1 sec is the CW laser input and the third one perform the output of the optical signal. Suppression ratio of the MZM was set to 30 dB which characterizes the ratio of two optical power level created by the optical source (Raj and Mascreen, 2015). There is no amplifier was used with downstream sender first is to spread out into supplier fiber to conciliate the big waste that came with long covered area then increase both 1577 and 1490 nm signals, we depend on the laser power only to see how long the signal can reach.

ODN: Optical Distribute Network which is entirely passive and consist of power combiner used to add the downstream signals by Combine two or more waveguides onto a single waveguide fiber optic represent. The passband of the project has a reference wavelength = 1310 nm in the middel 1300 and 1320 nm which has dispersion = 0, attenuation = 0.2 dB per km, fractional Raman contribution = 0.18. The effective core area (Aeff) of fiber = 80 um^2 and finally nonlinear refractive index (n2) = 26×10-21m^2/W. Passive power splitter which are analysed by ONU after divided the main signal into two optical signals, respectively. Optical attenuators are simulating the loss that is equivalent due to splice connections and all connector on the optical link.

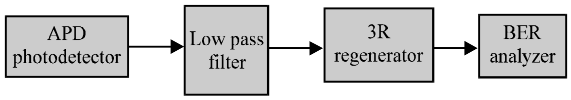

Fig. 7: Receiver component of GPON (Alameen, 2017)

ONU: As shown in Fig. 7, the receiver consists of an:

BPF is (Band Pass Filter): A filter for optical communication that demonstrate the influence of diplexer that occur in the receiver with frequency 1577 and 1490 nm having bandwidth = 0.07 nm.

APD is (Avalanche Photo Diode): With responsivity set to 1 A/W. Responsivity (Rd) measures the electrical output per optical input and can be expressed in terms of a fundamental quantity called the quantum efficiency (n). Dark current was set to 10 nA. APD photodiode PIN Photodetector receivers signal at 1577 and 1490 nm.

LPBF (Low Pass Bessel Filter): The signal shpuld have a cut off frequency of 0.75×bitrate and there is a loss in power due to filtering. The 3R regenerator connected after receiving and filtering the signal. The 3R regenerator has three output gates, the first output gate is the bit sequence, the second is a reference signal and the last is the output signal. These signals must have connected straight to the BER analyzer. The 3R regenerator is linked straight to the BER analyzer and used to regenerate the electrical signal.

BER (Bite Error Analyser): Analyzer use analyse the performance by regenerate the signal and drown diagram such as eye opening, eye diagram, Q value and BER, so, he works as a visualizer (Shea and Mitchell, 2007) by the ITU-T G.984 is teetered the downstream sender guidance of the 2.5 Gb/sec data stream. In this a network, the design achievement was wanted to be $BER<10^{-10}$(Li *et al*., 2014a, b). So, the maximum range of 20-90 km must be done (Kaur *et al*., 2017).

Non Return to Zero (NRZ) format: We can simply list the characteristics of NRZ:

- NRZ format in the contrast to RZ format, it demands minimum electrical bandwidth for equipment in the receiver and sender side
- NRZ as an application is very simple, higher spectrum effectiveness and minimum cost which can be applied closely into the Wavelength Division Multiplexing (WDM) and Synchronous Digital Hierarchy (SDH) system
- NRZ is not sentient to laser phase noise
- NRZ has a superior dispersion tolerance due to his bigger spectrum performance than RZ (Kaur *et al*., 2014)
- The NRZ as well own a narrow optical spectrum range
- Has high sensibility for Inter Symbol Interference (ISI) (Hazra *et al*., 2013)
- The RZ can be the extreme main data format as contrast to NRZ modulation format which cannot

The disadvantage of NRZ is that the transport doesn't come back to zero in the midst of two codes, the sensibility for transport waste. So, it is not convenient with big velocity and the additional long range transport (Hazra *et al*., 2013).

Return to Zero (RZ) format: RZ modulation has turn into a common solution for 2.5Gb/sec systems in the contrast to NRZ (Kaur *et al*., 2013; Hazra *et al*., 2013). RZ are better than NRZ in particular system as we will prove that, here, some characteristics of RZ. RZ has the lower dispersion tolerance (Verma *et al*., 2016; Kaur *et al*., 2014). RZ is applied in the big velocity of 40 Gps optical transportation system because of data format of RZ has a various transition in the code bit all the time, so, the transition region which link "1" amplitude of electric field has the divide time cover. So, it can fetch additional optical signal used in the receiver for unscramble. RZ is the weakest average of optical power. An increase signal-to noise ratio, so that, reduce bit error rate that NRZ encoding. Offers good immunity to fiber nonlinear effects. In the single-channel transport system, RZ modulation format is has a minimum sensitive to Inter-Symbol Interference (lSI), RZ code is also more helpful to clock recovery. Because has a duty cycle lower than 1 in the contrase to the NRZ which has "1" is a whole, so, the eye pattern of RZ code extension will be largerand this led to the superior capability of ant error code execution and raise both the robustness to PMD and fiber non-linearities. RZ pulse minimize its spectral efficiency Because of his frame shape spectrum.

RESULTS AND DISCUSSION

As we mention before our design (GPON-FTTX) is implemented using OptiSystem. This part shows the implementation details for the results. Also, discusses results and some problems or concepts had met during the implementation of the system. The design performance will be scanned for analysing the prospect of this co-existence. By changing the longitude of the fiber for (20, 30, 40, 50, 60, 70, 80, 90, 100 km) as shown in Fig. 8.

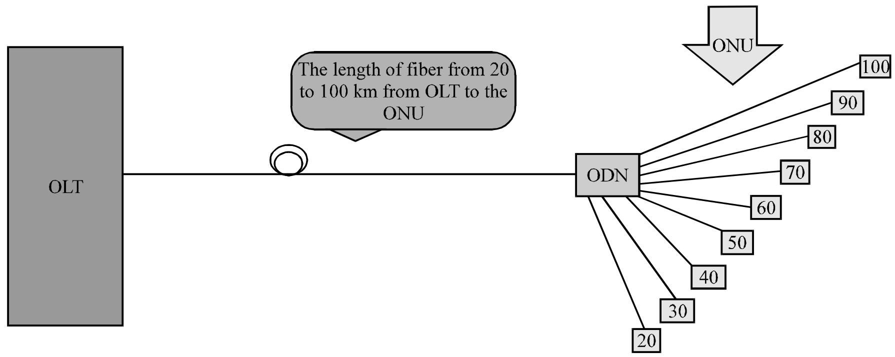

Fig. 8: GPON-FTTx representing a distribute ONU among available distance

We want by connecting the GPON system that used in FTTX and see how large the area can cover without any kind of amplifier, also, we want to check the better wavelength performance among the two we used. operating wavelength used for downstream direction (1490-1557), we used power of CW laser of OLT (-5, -3, 0, 3, 5 dBm). After we know the distance can cover, during the design of any area (specialty town and village) will know how may OLT, we will need in the design. We mention town and village because the is a limit infrastructure around the house (electricity), so using our passive design from the OLT-ONU without any kind of amplifier in the ODN will be just perfect. It is for sure that RZ data format is excellent as compared to traditional NRZ data format specially in our design purpose (Fig. 9, 10):

- 6.10 dB at 1577 nm at a distance of 90 km in RZ format as shown in Fig. 11a and the overall loss of power is 33.88 dB
- 6.26 dB at 1490 nm at a distance of 90 km in RZ format as shown in Fig. 11b and the overall loss of power is 34.6 dB
- 11.81 dB at 1577 nm at a distance of 40 km in NRZ format as shown in Fig. 11c and the overall loss of power is 20.14 dB
- 6.52 dB at 1490 nm at a distance of 70 km in NRZ format as shown in Fig. 11d and the overall loss of power is 27.17 dB
- We talk here about a good signal has Q-factor ranging from 6-7, the BER is obtained as 10^{-9}-10^{-12} (Hazra *et al*., 2013; Chen *et al*., 2013)

The fiber link consist of 90 km principle Single Mode Fiber (SMF) and to change the received optical power a variable optical attenuator is needed. These (33.88, 34.6, 20.14 and 27.17 dB), respectively put in your consideration all the loss power effects in the fiber such as attenuation and dispersion (Shea and Mitchell, 2007). To evaluation the implementation, the Q-factor and BER.

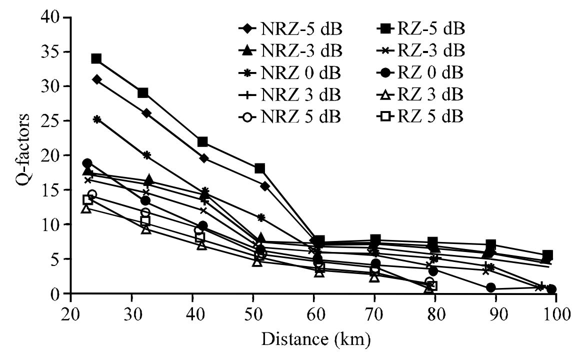

Fig. 9: A chart shown the Q-factor versus distance for varying bit rates (2.5) and data formats (RZ and NRZ) for 1490 wavelength (nm)

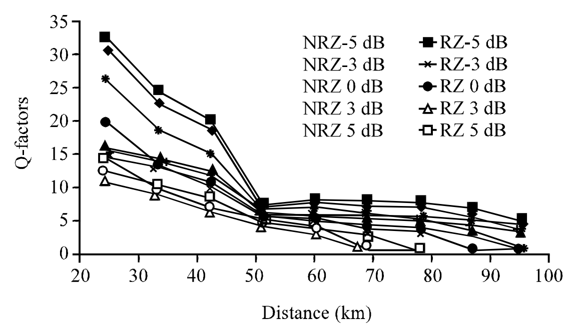

Fig. 10: A chart shown the Q-factor versus distance for varying bit rates (2.5) and data formats (RZ and NRZ) for 1557 wavelength (nm)

We have been considered from the eye diagrams of electrical scope for downstream signals. Figure 9 shows Q-factor versus distance for constant bit rates equal to 2.5 and data formats RZ and NRZ as a function of distance for downstream Fig. 9 at 1490 nm and Fig. 10 for1577 nm.

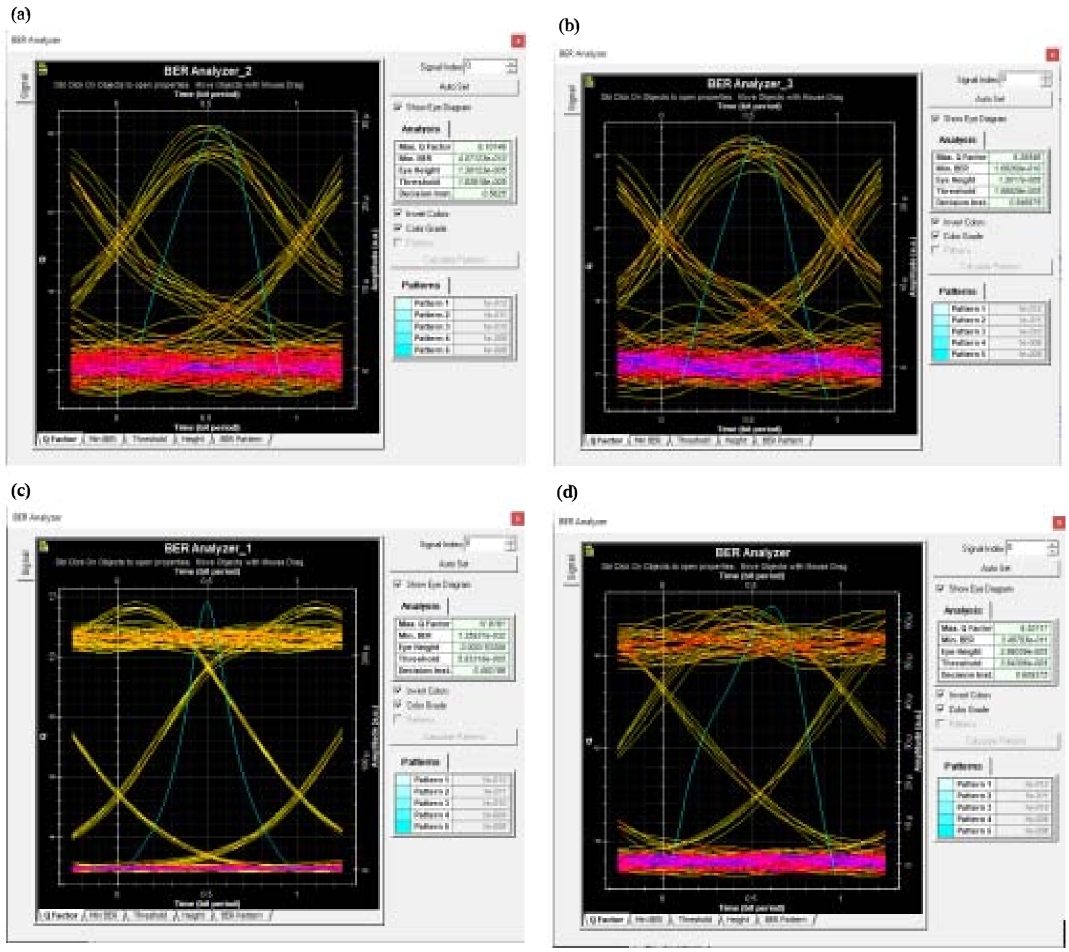

Fig. 11: The eye diagrams different range for downstream: a) 1577 nm 90 km in RZ; b) 1490 90 km in RZ; c) 1577 40 km in NRZ and d) 1490 70 km in NRZ

In the both Fig. 9, 10 it can be visible for the two the data formats that as Q-factor decreases up to certain limit (50-60 km) it starts raising a little bite then it continues to fail until it reaches 0 Q-factor. This may be knowing the minimum powers, the achievement of the design gets better with the raise in input power (specially, between 3 and 5 dB). In spit that, at when powers increase, the wavelengths resort to overlap each other leading to more control of non-linearities and so, the Q-factor after 3 dBm is minimize. As well it could be seen from the picture that RZ gives higher effectiveness in the contras to NRZ.

Comparing the outcome of RZ and NRZ formats in Fig. 9, 10, obviously that 2.5 Gb/sec in RZ data format gives the best implementation then follow by NRZ format. Also, it gives excellent performance at 2.5 Gb/sec. In Fig. 9, it is clear from diagram that at 1490 nm, the design works effectively for 2.5 Gb/sec data rates for the range up to 90 km. While the 1557 nm doesn't go well as 1490 nm as shown in Fig. 10 it is reach up 40 km in NRZ and 70 in RZ data format do preferable than NRZ. In the existence of SPM, these pulses unable afford pressure and do greater than NRZ pulses. The less wanted Q-factor for correct transport is 6.0 dB at BER 10^{-9}. These value display that the: efficiency of RZ is so good compared to NRZ as data format for downstream transmission. With the same data format NRZ the performance of wavelength 1490 has a better performance and reach longer distance then 1557. With same distance and different wavelength NRZ consume less power than RZ (this result from power meter). Figure 11 a-d show the eye diagrams for 1490 and 1577 nm in RZ and NRZ format at different range for downstream. These outcomes moreover accept the outcome of the previously discussion.

CONCLUSION

We measured the prospect of RZ and NRZ modulation formats in the co-existence of 2.5 G GPON-FTTX system for bigger bit rates and passive service with a long distance to cover. It is found that, the simulative analysis has shown that RZ modulation format is excellent compared to the traditional NRZ modulation format as it displays the best immunity to fiber non-linearities and average peak power, it is also evident from results that RZ can reach up to 90 km with 5 dB power source and with any wavelength (1557-1490 nm) and beyond which BER is above 10^{-9}(6-7 in Q-factor). Overall loss is 33.88 dB for 1557 nm and 34.6 dB for 1490 nm dB. These loss power taking into consideration all pertinent physical effects in contrast the NRZ with power 5 dB has reach 40 km with 1557 nm and with power loss is 20.14 dB and 70 km with 1490 nm with power loss is 27.17 dB.

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