ONU-Internetworking in Passive Optical Networks: Proposal of a New Strategy for High Bandwidth

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Abstract - *For the ever increasing bandwidth hungry applications, Passive Optical Network (PON) is assumed to be an effective solution. It is a system which leads optical fiber cables and signals all or most to the end user. It is a technology of telecommunication that implements a point to multipoint architecture and utilizes unpowered components to enable a single fiber to serve multiple end users without the need of having individual fibers between the customer and the hub. We propose and demonstrate a Remote Node (RN) architecture that enables direct Optical Network Unit (ONU) internetworking within a group and/or with another group by using Fiber Bragg Grating (FBG) array in Time Division Multiplexed PON (TDM-PON). The specific wavelength assignments are used for the traffic intended for various virtual private groups formed in the network and to be received by the specific group of ONUs, for overall broadcasting and to be received by all ONUs in the network. The proposed architecture supports downstream, upstream and direct inter-ONU transmission simultaneously.*

Key Words: Passive optical network (PON, Optical network unit (ONU), Bandwidth, BER (bit error rate))

1. INTRODUCTION

With the turn of the century, we can witness tremendous innovations in the area of telecommunications which have too much impact on our day to day life. So many factors are responsible and drive these innovations. The very first is the never ending requirement for increasing network capacity [1]. The enormous advancements of the World Wide Web and the Internet in context of the resources and the time usage, and hence the bandwidth utilized by each user, is a main constraint. The traffic internet traffic has escalated speedily for a very long time. Concurrently, the broadband access technologies that include Digital Subscriber Line (DSL) and modems on cable networks that facilitate bandwidths per user of the order of 1 Mbps, have been set up generally. Fiber to the home (FTTH) solution has shown the greatest penetration in the market. Simultaneously, current businesses depend on the faster networks for their businesses. There is a substantial relation between the bandwidth cost and the increase in demand. The advancements in the technology have led to continuous reduction in cost of the bandwidth. This results in increased

use of bandwidth due to launch of new applications and impact on usual pattern. Data transfer services have been dominant and have capabilities of providing QoS to the real-time applications. These factors have major contribution in the development of Optical Networks with tremendous capacity and their noticeably quick commercial deployment into real world from the research laboratories. Currently Optical Networks are being deployed in a wide extend to meet the ever increasing requirements of high date rates of number of users. Today, so many public networks are being employed by the service providers [2]. Long-haul networks transfer huge amount of data compared to any other network and over large distances that can cover over hundreds and thousands of kilometres connecting the continents and countries distributed geographically worldwide [1] [2]. Typical rates of operation of these networks are 2.5 Gbps and 10 Gbps. However, the efforts are going on to device 40Gbps transmission system to cater the higher bandwidth requirements for applications requiring higher bandwidth requirements. Metropolitan (or Metro) networks may be simply defined as connecting agent between first-mile network areas (access networks) and long-haul networks. Access Network is used to connect the end user or customer directly to the ISP (immediate service provider) and through the data carrier network, to other networks such as the Internet. It feeds Metropolitan Networks by gathering data. It covers a distance of 0 to 20 km [3].

Passive Optical Network (PON) [4-6] consist 3 portions namely an Optical Line Terminal (OLT) or Central Office (CO), Remote Node (RN) or Optical Distribution Network (ODN) at mid-path and an Optical Network Unit (ONU) or Optical Network Terminal (ONT) at end [4]. An OLT acts as the endpoint hardware device in a PON. It includes a gateway router (GWR), central processing unit (CPU), PON cards and a voice gateway (VGW) uplink cards. Equipment at the customer end is called ONU. In PON, only OLT and ONUs use active (powered) components while the RN used passive (unpowered) components like Power Splitters (PSs), Power Combiners (PCs), Arrayed Waveguide Grating (AWG), Fiber Bragg Grating (FBG), etc. and hence it is called passive network. In PON, TDM-PON [7] is a concept used for access and long haul networks in order to accommodate more number of users in a network. In the uplink, all ONUs share the same fibre through Time Division Multiple Access

(TDMA) by transmitting the signal in specified time duration, for downlink direction, the OLT coordinates the ONUs to pass frames specified for particular ONU for specified time interval.

ONU-internetworking can be done in many different ways. But it can be genrally categorized into two techniques: 1. Inter-ONU Broadcast, 2. Formation of VPGs of ONUs. As far as inter-ONU broadcast is concerned, the ONU can communicate to ther OUNs, directly within the network without the need of being co-ordinated by the OLT. Thus, the traffic which is intended for inter-ONU communication is redirected back from the RN, broadcast to the entire ONUs available in the network. Hence, the traffic is received by the entire ONUs. Based on ONU-internetworking, there are a number of techniques that include virtual ring network [22], reflection mechanism using FBG [14], [16] loop-back mechanism [17], [20], use of RF carrier [19], reflective waveband grouping [22], Electronic-code division multiple access (E-CDMA) [22], Sub Carrier Multiplexing (SCM) technique [18], Dynamic waveband reflection, two stage PONs [19] and many more have already been employed.

2. PROPOSED ARCHITECTURE

We have proposed a Flexible Remote Node Architecture for Energy Efficient Direct ONU Internetworking in TDM-PON. In the proposed PON is considered to be founded on TDM-PON manner. For uplink, all ONUs share common fiber through TDMA by transmitting the signal in a specified time interval, and in the downlink direction, the OLT coordinates the ONUs to transmit frames particularly corresponding to specific ONU in the particular time interval. As shown in Fig. 1, the architecture involves an OLT, a RN and number of ONUs. The OLT transmitter includes a continuous wave LASER, Pseudo random binary sequence (PRBS) generator, Non-return to zero (NRZ) pulse generator and Match-Zehnder modulator (MZM). The MZM modulates the LASER power with the NRZ converted PRBS and transmits in the downstream. An OLT receiver includes a Gaussian optical filter, PIN photo-detector, low pass Bessel filter and BER analyzer. The upstream signal wavelength is filtered by the filter, detected via PIN diode and analyzed by the BER analyzer. The ONU transmitter and receiver are same as that of the OLT except the Gaussian filter and LASER which is tunable in case of ONU in order to receive and transmit at the possible tunable wavelengths.
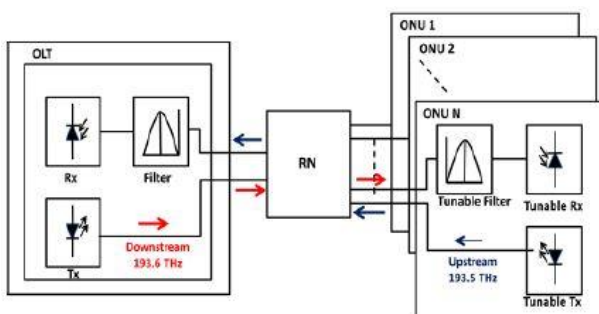

Fig. - 1 OLT and ONUs with a Transmitter and a Receiver

Now, if we consider the generalised proposed design each ONU in a network corresponds to a particular wavelength λu for upstream traffic and λi for inter-ONU traffic. For downstream transmission, a particular wavelength λd is employed at the OLT. Also there are N - number of VPGs which can be formed by the same type of users in the network and each VPG comprise of M ONUs (end users) as depicted in Figure 2, where M and N are integers.
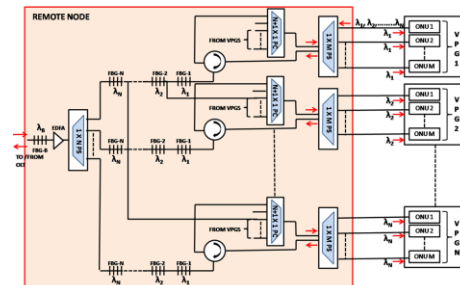

Fig. – 2 Generalized Configuration of Proposed Remote Node

We have taken into account every VPG to be an individual PON branch for maintaining security, lower obligation of power and relaxed power budget matching. For communication with N VPGs, employed wavelengths are λi (i=1,2,.....,N) and are routed to specific VPG depending on the wavelength arrangement that can be found from equations (1), (2) and (3).

$$\lambda = \lambda_I \text{; if s=d}$$

$$\lambda = \lambda\_I + x * \omega \text{ ; if s < d}$$

$$\lambda = \lambda_I + [N - x] * \omega \text{ ; if s > d}$$

Where, *s & d* belong to source & destination VPG numbers, is the wavelength spacing among 2 successive wavelengths, *N* is the entire no. of VPGs in the network and *x* = Mod (source VPG number- destination VPG no.).

The planned RN comprises of N of 1 x M bidirectional power splitters for broadcasting the downstream and as inter-ONU traffic so as to associate upstream traffic, N no. of (N+1) x 1 power combiners are employed to join a regular downstream traffic via circulator and the N reflected inter-ONU traffic of all N VPGs. The circulator is employed for separation of downstream as well as upstream signals to permit the proposed framework for bidirectional communication. N no. of FBG arrays (each array consist cascaded FBGs) are linked to each branch. For every branch has N cascaded FBGs, it is proficient of reflecting N wavelengths. The Bragg wavelength for FBG within this array is λi for FBGi where i=1,2,.....,N. The wavelength employed aimed at the communication from a particular ONU in any VPG to corresponding VPG is described by equations given above.

A FBG tailed by 1xN power splitter is employed from OLT side of RN so that it broadcasts overall signals. Essentially, Bragg wavelength for this particular FBG is established as λB and each of the inter-ONU signals are transmitted at λB are reflected and broadcasted to every PON branches. An erbium-

doped fiber amplifier (EDFA) is in order to reduce the power losses are employed which simultaneously achieves the power budget range easily. However, involving Duo-binary (DB) coding power budget may be extravagantly enhanced [31].

2.1 SIMULATION FRAMEWORK AND WORKING

For simulation of proposed architecture, a PON architecture system consisting 4 VPGs (N=4) is taken into account and simulated on OptiSystem 13.0. Every ONU and OLT contains of 1 transmitter and 1 receiver for transmission and reception of the signals respectively as shown in Figure 3.1. Moreover each VPG consists of ONUs (M=2) as revealed in Figure 3.3. All ONUs are assumed to be present within the range of few 100's of meters distant from the RN, connected to RN via optical-fiber.

Table -1: Simulation parametric used in Optisystem 13.0

Component	Downstream	Upstream	Inter-ONU
Data Rate (Gbps)	10	2.5	2.5
Modulating Frequency (THz)	193.6	193.5	193.1, 193.2, 193.3, 193.4 & 193.9
Fiber Length (km)	20	20	Varies from 0.1 to 0.4
Fiber Attenuation Constant (dB/km)	0.2	0.2	0.2
Fiber Dispersion (ps/nm/km)	16.75	16.75	16.75
Cut-off Freq. of Low Pass Bessel Filter	0.7xBit rate	0.7xBit rate	0.7xBit rate

In down-stream transmission, OLT actions as transmitter device whereas ONUs actions as receivers. At OLT, for traffic generation, a binary sequence of period 27-1 is generated arbitrarily at 10 Gbps by spending a PRBS NRZ generator besides modulated at frequency=193.6 THz by Mach-Zehnder Modulator (MZM). This resulting MZM is fed to 20 km fiber with attenuation constant of 0.21 dB/km and dispersion of 16.875 ps/nm/km. Further, it propagates to ONUs through EDFA where it is amplified in order to balance the losses, 1 x 4 PS, 3-port circulator, 5 x 1 PC and 1 x 2 PS. Hence-forth, downstream transmission is broadcasted to every VPGs

(ONUs) and received by every VPGs (ONUs). Insertion losses of PS and PC are calculated based on 3Log2(K), where K represent the no. of ports. Considering, for 4 port power splitter, the insertion losses are at 6 dB. At each ONU, downstream signal will be received by the receiver comprising of a Tunable filter for reception of the likely Tunable frequency, a PIN photo-detector with responsivity of 1 A/W and dark-current of 10 nA. A Low pass Bessel filter of cut-off frequency= 7/10 times the Bit rate and a BER analyser is employed to analyse the received signal. BER analyser delivers the value of BER, the quality-factor and the eye-diagram at the tx. Rate. The involved simulation parameters used in the simulation of above system are given in Table 1.

For up-stream data tx., ONUs performs as transmitters besides an OLT performs as an receiver. The traffic on behalf of upstream is produced at 2.5 Gbps also is modulated at 195.5 THz in a comparable method as clarified beyond the down-stream transmission. So, for this simulation work we have taken into account only a single ONU for transmission. Flexible RN architecture along-with direct inter-ONU communication competence is depicted in Fig. 3.3, where we have employed four 1 x 2 PSs, four 5 x 1 PCs and four circulators. For rerouting of intern ONU traffic, 4 FBG-arrays of 4 back to back FBGs are employed. The Bragg wavelengths of FBG-arrays are measured as λ1, λ2, λ3 and λ4 (i.e. 193.1 THz, 193.2 THz, 193.3 THz and 193.4 THz) for FBG 1, FBG 2, FBG 3 and FBG 4, correspondingly. The reflected wavelengths after each array is connected to specific PC allowing the wavelength projects based on (1), (2) and (3) as given in the Table I. For convenience of understanding, the wavelengths are depicted using specific colours i.e. red colour for tx. from VPG1, yellow from VPG2, green from VPG3 and blue from VPG4 in Fig. .3.

Table -2 Wavelength Projections for Four V-PGs

Destination VPG ⟶ Source VPG ⟶	V-PG 1 λ (THz)	V-PG 2 λ (THz)	V-PG 3 λ (THz)	VP-G 4 λ (THz)
V-PG 1	193.1	193.2	193.3	193.4
V-PG 2	193.4	193.1	193.2	193.3
V-PG 3	193.3	193.4	193.1	193.2
V-PG 4	193.2	193.3	193.4	193.1

In case of inter-ONU communication, we take into account ONU 1 by VPG 1 is transmitting on wavelength 193.1 THz (λ1) as shown in Figure 3.3. This wavelength will reach up to FBG 1. For Bragg wavelength of FBG 1 is 193.1 THz and FBG reflects any signal at its Bragg wavelength, it reproduces same wavelength. Depending on wavelength task specified in the Table I, this wavelength is transmitted to VPG 1 only as

indicated by red arrow in Figure 3.3. Hence, here we are achieving intra-VPG communication i.e. within VPG itself. Now, for the inter-VPG communication, we considered that the same ONU 1 is transmitting on wavelength 193.2 THz (λ2) as shown in Figure 3. This wavelength will reach up to FBG 2. In the same manner as previous case, it will be reflected from FBG 2. Based on the wavelength assignment, this wavelength remains transmitted to VPG 2.
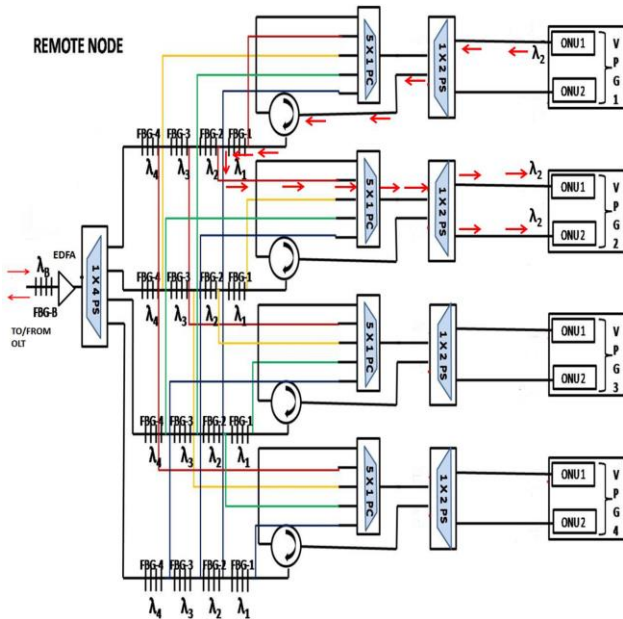

Fig. - 3 Strategy of the Remote Node considered for Simulation showing Internetworking with other VPG (inter-VPG communication)

Hence, here we are achieving inter-VPG communication i.e. with other VPG. Likewise, depending on wavelength transmitted by any ONU from VPG 1, communication with further VPGs is too likely on other wavelengths as shown in Table I. In general, any ONU from any VPG is able to communicate with all ONUs of any VPG including the transmitting VPG also. That means, intra-VPG as well as inter-VPG communication is possible in this architecture.

Apart from that, for the complete broadcasting, FBG situated at RN near OLT side performs an important role. It has Bragg wavelength 193.9 THz (λ_B). If any ONU positioned in some VPG transmits at 193.9 THz as shown in Figure 3.4, this wavelength is reproduced after this FBG and coming back to the power splitter, gets split and broadcasted to every 4 PON branches (VPGs). Thus, all VPGs and hence, all ONUs available in the network receives that wavelength. We achieve overall broadcasting in this way in this architecture.

3. RESULTS AND DISCUSSION

Here, the results obtained by using OptiSystem 13.0 are discussed. For analysis of the proposed system performance for 20 km fiber and B2B has been taken into account for the up-stream and down-stream data transmission. Similarly we have analysed the inter-ONU transmission rate for different ONUs. The plots for bit error rate (BER:Ratio of bits received in error to the total bits transmitted) versus received power

are obtained for down-stream, up-stream and interONU traffic shown in Figure 4, Fig. 5 and Fig. 6, respectively. From the obtained graphs it can be deduced that BER significantly advances with upsurge in received power and we are obtaining the waterfall like curves.

Also in Fig. 4 and Fig. 5, it can also be perceived that a power forfeit of about 0.5 dB and 0.2 dB respectively for down-stream and up-stream transmission due to Rayleigh back-scattering besides nonlinear effects happening in optical fiber during transmission. The strength of down-stream power penalty is more than up-stream power penalty due to high data in down-stream as compared to up-stream transmission.
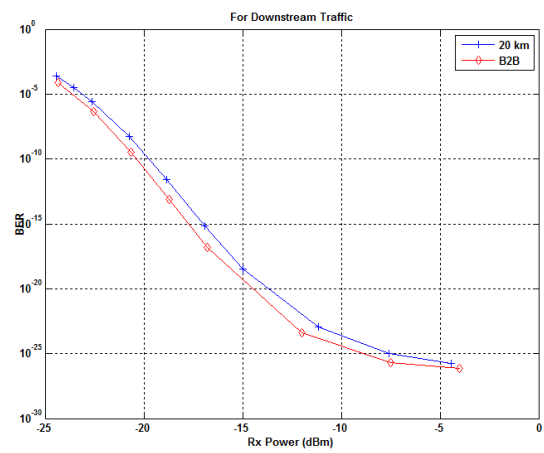

Fig. - 4. Down-stream transmission at 10 Gbps

We have provided the eye diagram also for the reference to see the quality of reception for down-stream, up-stream and inter-ONU communication in Fig. 5, Fig. 7 and Fig. 10, at the value of BER equal to 10^{-9}. Here, we can observe the clear eye opening. In ideal case, eye-diagrams would be similar to that of rectangular boxes. But in practical case, communication systems are not that perfect, results in the transitions that do not fit exactly on another, and resulting in an an eye-shaped pattern. The dissimilarities in amplitude and timing from bit to bit makes the eye opening to compress.

In Fig. 8 is shown that the BER enactment of Inter-ONU communication for transmission of data from ONU1 to further ONUs within network for 4 different wavelengths that include 193.1 THz, 193.2 THz, 193.3 THz and 193.4 THz for VPG-1, VPG-2, VPG-3 and VPG-4, respectively. Due to the common fiber distance between RN and ONUs i.e. within 100 m to 500 m, the obtained BER is near about similar for every transmission provided the received power is same. Figure 4.6 shows BER performance of the inter-ONU communication from ONU 1 of VPG 1 TO VPG 2, separately for ease of understanding.
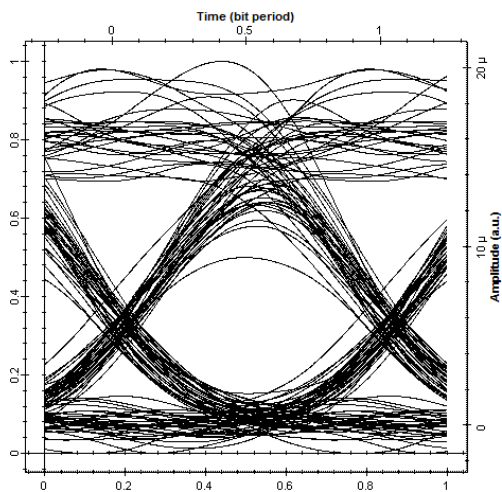
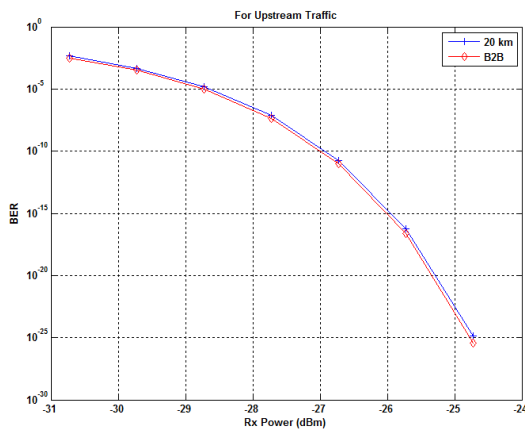**Fig. -** 5 Eye Diagram for the downstream communication at BER of 10⁻⁹
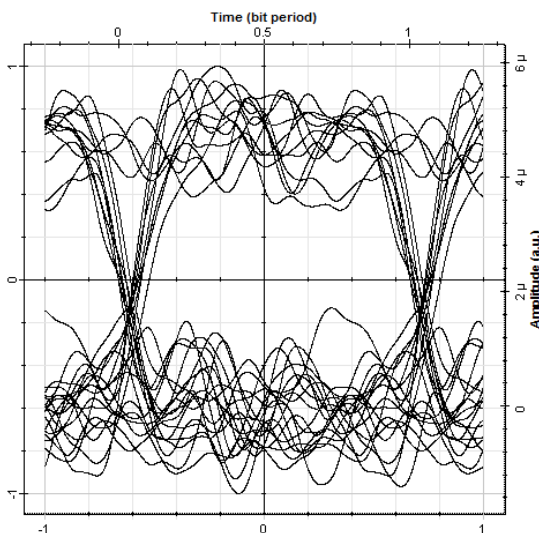

Fig. - 6 Up-stream transmission at 2.5 Gbps

Fig. - 7 Eye Diagram for the upstream communication at BER of 10⁻⁹

In comparison of inter ONU transmission for up-stream transmission and down-stream transmission, it implies that inter-ONU communication needs minimum received power for the same amount of BER performance. This is because of

evading non-linear properties happening within the fiber due to reflection from the RN itself. Consecutively it can be inferred that, for interONU transmission, small input optical powers leads to the identical BER performance. Henceforth direct interONU transmission decreases the general power consumption of the system. Moreover, direct inter-ONU communication delivers the chance to decrease the latency and exploits the bandwidth proficiently since it is not transmitted to OLT with up-stream transmission and back to the ordained ONUs with down-stream transmission.
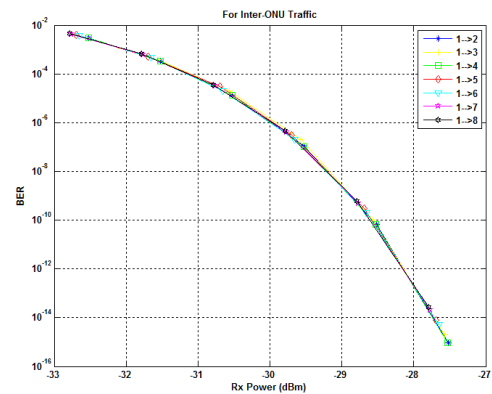

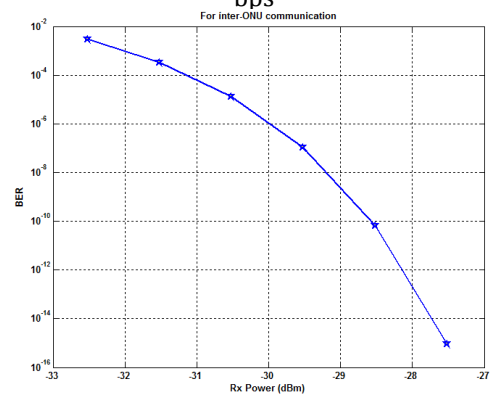**Fig. - 8:** The scenario of Inter-ONU transmission at 2.5 G bps

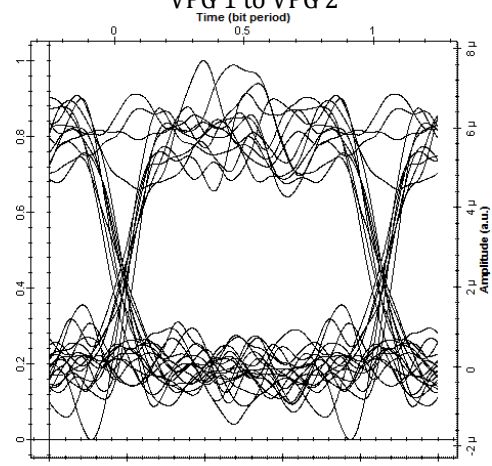**Fig. -** 9 The scenario of inter-ONU communication from VPG 1 to VPG 2

Fig. - 10 Eye Diagram for the inter-ONU communication at BER of 10⁻⁹

The frequency range of received signal for general broadcasting at 193.9 THz for interONU transmission is shown in Figure 4.8. Here, only ONU-1 of VPG-1 is transmitting besides all further ONUs of all VPGs are receiving. Some other ONU accessible within network after some VPG might transmit in alike manner and require overall broadcasting. This figure also displays that the received power may effortlessly fulfil the vital power requirement to satisfy the receiver sensitivity for the decent BER performance.
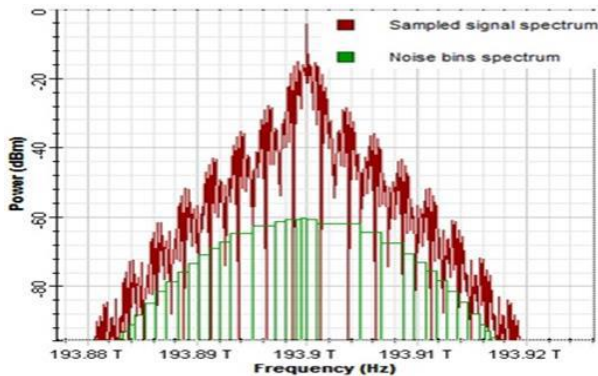

Fig. - 11 For Inter-ONU transmission, received spectrum at ONU 1 of VPG 1 for overall broadcasting at 2.5 Gbps

4. CONCLUSIONS

In this work, we proposed and implemented a flexible RN system topology that delivers concurrent down-stream, up-stream and inter-ONU transmission. By employing the architecture, direct inter-networking from one ONU to further ONUs present with in the same VPG or any other VPGs is realized, which offers resourceful operation such as power and bandwidth. Proposed architecture too shrinks the transmission latency amid ONUs for inter-ONU communication. The performance of the planned architecture is tested with the simulation results by OptiSystem 13.0. It delivers a decent BER performance for down-stream, up-stream and inter-ONU transmission. Moreover, in case of inter-ONU communication we are getting less BER for the same received power as compared to upstream and downstream transmission. This work can be extended by modifying the architecture in such a way that it provides direct ONU communication for the case of one-to-one case means from any ONU in any VPG to any ONU in any VPG, also.

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