Indian Journal of Pure & Applied Physics
Vol. 60, March 2022, pp. 254-260

# Design and Analysis of a Bi-directional Line Switched Ring for High-Speed Super Dense Communication

Parashuram[a], Chakresh Kumar[a]* & Ghanendra Kumar[b]

[a]University School of Information, Communication & Technology, Guru Gobind Singh Indraprastha University, New Delhi-110 078, India

[b]Department of Electronics and Communication Engineering, National Institute of Technology, Delhi-110 040, India

*Received 19 January 2022; accepted 24 February 2022*

Performance of 500 x 10 Gbps super dense Bi-directional Line Switched Ring (SD-BLSR) has been analyzed with channel spacing of 25 GHz. For the first time, best of our knowledge, acceptable rating has recorded at -25 dBm input power and data rate of 30 Gbps with the help of RAMAN-EDFA hybrid optical amplifier (HOA) without using any dispersion compensation and cost effective techniques. Final outcome has also declared to control the channel traffic for present optical communication.

**Keywords:** SD-BLSR, OADM, Q-factor, BER, HOA

## 1 Introducation

Demands of high-speed optical signal transmission are increasing day by day due to revolutionary change in optical communication. Further, demands of number of users in terms of different aspect can only be accomplished with the help of super dense bidirectional line-switched ring (SD-BLSR), which is also called *self-healing ring*[1-5] to increase the bandwidth with the support of productive high-capacity time division multiplexing channels[6-7]. Super dense wavelength division multiplexing (SD-WDM), facilitates us to transport more than one wavelength channels through the same fiber. Just because of, this is highly appreciated for long haul optical communication transport network.

Transmission of dense channel is only possible with the support of hybrid optical amplifiers (HOAs) which have to link in the optical medium to maintain the best rating features.

In recent years, effect of semiconductor optical amplifier (SOA) was observed in place of erbium-doped fiber amplifier (EDFA) in terms of low power consumptions and cost effectiveness for small channel transmission[8-10].

In metropolitan city, data traffic at each node of optical add-drop multiplexer (OADM) is increasing disorderly in optical communication, which has been resolved by using the SD-BLSR ring.

Wagner *et al.*[11] explored the bus topology for 24 users and maintain the least loss with SOA, further, bit rate of 20 Mbps with the spacing of 0.5 km was also received for short distance communication.

Singh *et al.*[12] explored the different transport topologies such as star, bus, ring and tree with the rate of 10 Gbps for the node of 27. Amplification was done with the help of SOA for the distance of 1.1 km. But unfortunately, consideration of number of users was less and amplification of HOA was not considered. But this is also an important consideration for handling the optical signals traffic problem.

Singh *et al.*[13] evaluated the ring topology using SOA and declared that number of users got decrease at the saturation of optical amplification. This evaluation was got down for 27 nodes.

Kaur *et al.*[14] investigated the performance of ring network topology for 60 users using SOA. Furthermore, this network was only capable to support a smaller number of users with less bit rate. But this network has also been set the benchmark for future optical network.

Iannone *et al.*[15] proposed a model for 4 x 2.5 Gbps for 160 km wavelength division multiplexing (WDM) system. Performances were evaluated using four cascaded erbium-doped waveguide amplifier (EDWAs) and effect of power penalty was also observed for less than 1 dB.

Iannone *et al.*[16] demonstrated a model of WDM metro ring. It was shown the negligible effect of power penalty for upstream transmission using four cascaded SOAs.

So far, all of the above research articles have shown the representation for unidirectional ring.

*Corresponding author: (E-mail: chakreshk@gmail.com)

Unfortunately, if the link is failed or node is failed or cable is failed then whole process of communication will be affected, which is also an important consideration for future super dense optical network for handling the huge data traffic. So, in this paper, we have resolved the massive traffic problem by considering the SD-BLSR ring using the commercial RAMAN-EDFA hybrid optical amplifier (HOA).

Furthermore, reminder of this paper is arranged as gain analysis of hybrid optical amplifier in section II, description of simulative setup in section III, result and discussion in section IV and paper is summarized in section V accordingly.

**2-Gain analysis of Hybrid Optical Amplifier**

RAMAN amplifier is enabling technologies for long haul ultra-wide band optical communication systems. SRS (Stimulated Raman Scattering) is used in a RAMAN amplifier, when an intense pump beam propagates through silica fibers. Raman gain arises because energy can be transferred from pump laser (Optical beam) to a weak signal that is downshifted in frequency. Merits of RAMAN amplifiers are minimized nonlinear crosstalk and very broad gain spectrum because of multi wavelength pumping scheme. Demerits of RAMAN amplifiers are the lower pumping efficiency at lower signal power and uses of expensive powerful lasers which can transfer high powers into single mode fibers. The gain of Raman is given in eq. (1)

$$G_R = e^{\left[\left(\frac{g_R}{A_{eff}}\right)P_p l_{eff} - \alpha_s l\right]} \quad \dots (1)$$

Where, $l_{eff} = {\left(1 - e^{\alpha_p l}\right)}/{\alpha_p}$ and $A_{eff} = \pi R_{eff}^2$ $\alpha_s$ is absorption coefficient for fiber loss at the signal, $\alpha_p$ is fiber transmission loss at pump wavelength, $P_p$ is optical pump power, $R_{eff}$ is effective core radius, $A_{eff}$ is effective core area of pump, $l_{eff}$ is effective length of the fiber, $l$ is the actual length of the fiber, $g_R$ is Raman gain coefficient and Raman gain efficiency is represented by $\frac{g_R}{A_{eff}}$.

Further, EDFA (Erbium Doped Fiber Amplifier) uses erbium ions ($Er^{3+}$) doped fiber of specific length. EDFA is passed through stimulated emission process and pumping is done by laser diodes to excite the erbium atoms to an upper energy scale. The main demerit of EDFA is that its gain spectrum with depends on wavelength which results in a narrow bandwidth around 1550nm and also it is not flat. But it can amplify the individual channels of a multichannel WDM signal simultaneously to avoid the cross-gain saturation. EDFA accomplishes high gain for a weak signal with low noise figure due to relatively long spontaneous carrier lifetime in silica fibers. Attenuation of DCF (Dispersion Compensating Fiber) can be compensated by reducing the linear losses at the channel ends after DCF using EDFA. The gain of EDFA is given in eq. (2)

$$G_E = e^{\left[\frac{h\nu_s}{P_{in}}\left(\frac{P_p(0)-P_p(l)}{h\nu_p} + \frac{P_S(0)}{h\nu_s}(G_E - 1) - \frac{P_{ASE}(l)}{h\nu_s}\right) - \alpha_s l\right]} \quad \dots (2)$$

Where, $P_p(0)$ and $P_p(l)$ are optical pump power at length $l = 0$ and $l$ respectively. $P_s(0)$ is represented by optical signal power at $l = 0$. Furthermore, $\nu_p$ and $\nu_s$ are frequency of pump and signal respectively. $\nu_s$ is frequency of signal, $h$ is Planck's constant, $P_{in}$ is power of input signal and power with amplified spontaneous emission at length $l$ is represented by $P_{ASE}(l)$.

To compensate the demerits, we need to combine the merits of RAMAN & EDFA amplifiers. Therefore, we have used the RAMAN-EDFA hybrid model. The gain of cascaded hybrid model can be expressed by combining the gain eq. (1) and eq. (2) in eq. (3) as,

$$G_{dB} = G_{R(dB)} + G_{E(dB)} = 10\log_{10}(\mathrm{G_R}) + 10\log_{10}(\mathrm{G_E}) \quad \dots (3)$$

**Bit Error Rate (BER) and Quality Factor (Q-factor)**

Bit error rate is one of the gain parameters to describe the quality of the data link for data transmission. BER is defined by the ratio of number of bits received in error ($b_E$) to total number of received bits ($b_N$) in the defined time interval. So, BER is defined in eq. (4) as,

$$BER = \left(\frac{b_E}{b_N}\right) \quad \dots (4)$$

Quality factor (Q- factor) is a parameter to measure the analogue quality of the digital signal with regard to SNR (signal-to-noise ratio). OSNR (Optical signal to noise ratio) is defined in eq. (5) as,

$$OSNR = 10\log\left(\frac{P_i}{N_i}\right) + 10log\left(\frac{B_m}{B_r}\right) \quad \dots (5)$$

Where $P_i$ is represented by maximum power of optical signal in the i[th] channel (watt). $N_i$ is interpolated value of the mean noise power (watt). In the similar way, $B_m$ and $B_r$ are spectral bandwidth and reference bandwidth (nm) respectively.

Quality factor includes all physical factors degrading the signal and causing BER. Value of Q factor is inversely related to the value of BER. Q factor is defined by the eq. (6) as,

$$Q = \frac{I_h - \gamma_{opt}}{\sigma_h} = \frac{\gamma_{opt} - I_l}{\sigma_l} \quad \ldots (6)$$

After considering the power levels of photo detector, quality factor is written in eq. (7) as,

$$Q = \frac{I_h - I_l}{\sigma_h + \sigma_l} \quad \ldots (7)$$

Where, $\gamma_{opt}$ is optimal value of the discussion level. $I_h$, $I_l$are current corresponding to the level of optical power on the photo detectors for log1 and log0 respectively. $\sigma_h$ and $\sigma_l$ are standard variance of logical level '0' and '1' respectively. Assuming the probability of occurrence of 'ones' & 'zeros' equally likely, BER and Q-factor can be related in eq. (8) as,

$$\mathrm{BER(Q)} = \mathrm{P(error)} = \frac{1}{\sqrt{2\pi\sigma_l}} \int_{\gamma_{opt}}^{\infty} e^{-\frac{1}{2}\left(\frac{i - I_l}{\sigma_l}\right)^2} \, di = \mathrm{erfc(Q)} \quad \ldots (8)$$

**3 Simulation Setup**

Systematic setup of two fiber super dense bi-directional line switched ring (SD-BLSR) topology is shown in Fig. 1. Each fiber used as working and protect bandwidth to control the working traffic which are indicated by P1 to PN and S1 to SN respectively. OADM nodes are connected with fiber span of 80 km in clock wise and anti-clock wise direction with the support of HOA to maintain the bidirectional communication with neglected effect of attenuation. Each node is controlled by transport controller (TC). For example-if the load of working traffic is higher, then shorted path will be decided by TC to send the traffic to the next node. Each node has OADM which consist of transmitter and receiver. This OADM system has 500x10 Gbps SD-WDM system with channel spacing of 25 GHz. Before each node, a signal analyzer block is placed to observe the optical spectrum of transmitted signals. Transmitter section is consisted of data source in terms of non-return to zero (NRZ) format, NRZ electrical drive, MZM electrical modulator and CW laser source with full-wave, half-maxima line width of 10 MHz for electrical to optical conversion.

Further, systematic arrangement of OADM is shown in Fig. 2.This model is arranged in the set of compound component which consists of transmitter and receiver. Drop channel of OADM is detected by optical filter with bandwidth of 50 GHz and PIN photo diode at the receiver end. Responsivity and quantum efficiency of PIN diode are set to 1 A/W and 0.798 respectively. Furthermore, electrical bessel filter bandwidth of 10 GHz used to filter out the electrical signals.

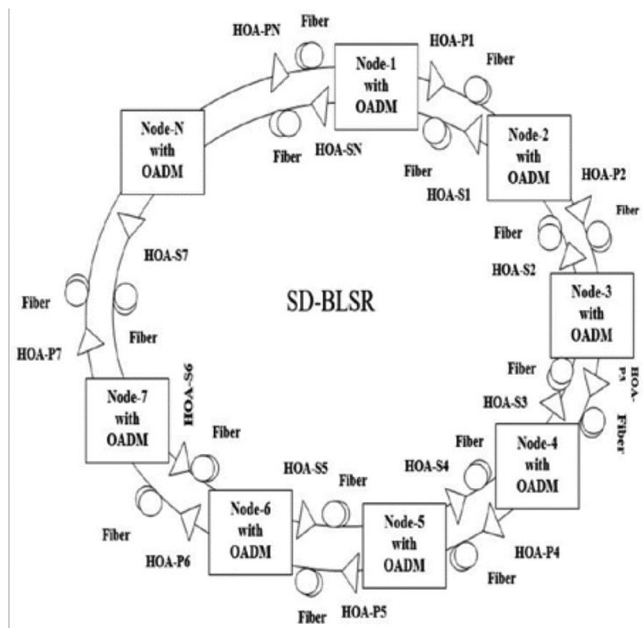


Fig. 1 — Schematic diagram of SD-BLSR

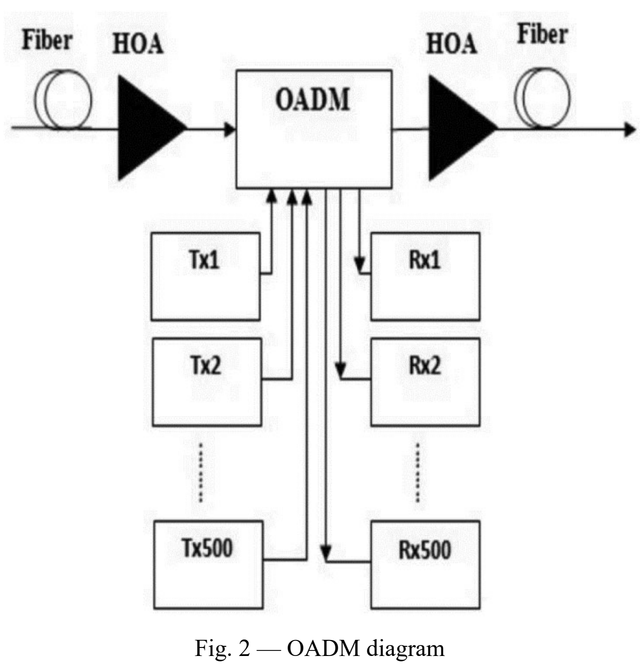


Fig. 2 — OADM diagram

Internal arrangement of OADM is shown in Fig. 3. It consists of super dense demultiplexer (SD-DMUX) and super dense multiplexer (SD-MUX) with optical cross switch (OXC) with corresponding input and output interfaces. One output of OXC goes to the client interface and one out of OXC goes to transport interface. Analysis of received signal is performed with the help of signal spectrum analyzer in terms of received power, bit error rate and quality factor. Further, required rating of used amplifiers for bi-directional ring is also given in Table 1 and Table 2 respectively.

## 4 Results and Discussion

Analysis of proposed model is mainly focused in terms of quality factor (Q-factor) and bit error rate

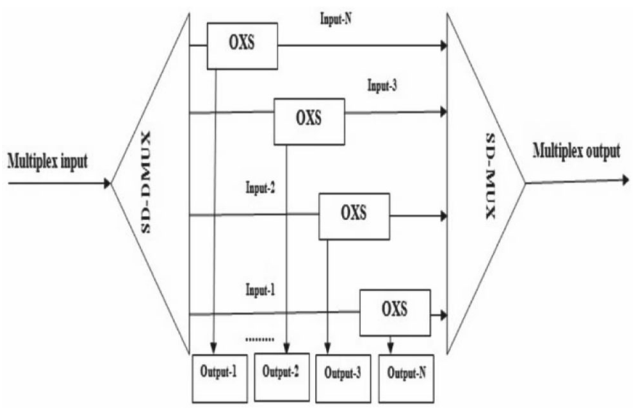


Fig. 3 — Internal arrangement of OADM

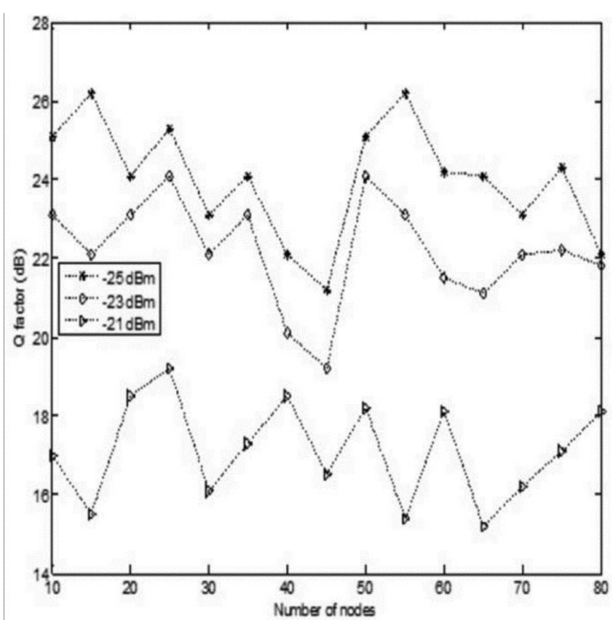


Fig. 4 — Q-factor with respect to number of nodes

(BER) from Fig. 4, 5 respectively. Injected input powers are given as 25.1 dB to 22.1 dB, 23.1 dB to 21.8 dB and 17.1 dB to 18.1 dB respectively for the power variations for -25 dBm, -23 dBm and -21 dBm from Fig.4. In the same way, recorded results are projected in terms of BER in Fig. 5. Here, it is noticed that variations in power, effect the performances of BER, subsequently as the power increases, rating in BER decreases and quality of signals are increased due to the minor effect of internal loss so injected power at -25 dBm is recorded the acceptable outcome for the features of Q-factor and BER.

Evaluation is carried out for the same characteristics with different date rate of 30Gbps, 25Gbps and 20Gbps respectively from Fig. 6, 7. Variations in quality factor are given as 25.1 dB to 20.1 dB at 30 Gbps, 23.1 dB to 15.8 dB at 25 Gbps and 17.1 dB to 14.1 dB at 20 Gbps from Fig.6. Here, it is observed that influence of fiber nonlinearity, loss and crosstalk are proportionally varies with number of data rate. But our proposed model is capable to maintain the acceptable rating quality factor and bit error rate with proposed hybrid optical amplifier (HOA). So, data rate at 30 Gbps delivers the required rating quality factor of 25.1 dB with acceptable bit error rate from Fig. 7. Eye diagrams of 500 users at 20 Gbps are also shown in Fig. 8(a,b). It is observed

Table 1 — Rating of RAMAN for bi-directional ring

| Parameters | Value |
|---|---|
| Gain shape | Flat |
| Amplifier length | 15.5 km |
| loss | 0.3 dB/km |
| Pump range | 1452-1485 nm |
| Force time domain | No |
| Injected power | 570 mW |
| Attenuation | 0.125 dB/km |
| Acceptable dispersion | 1.72 ps/nm/km |
| Noise | Yes |
| Required temperature | 300 K |
| Base wavelength for dispersion | 1552 nm |
| Simulation | $10^{-06}$ |

Table 2 — Rating of EDFA for bi-directional ring

| Parameters | Value |
|---|---|
| Gain of noise figure | 3.25 dB |
| Maximum small signal gain | 45.26 |
| Noise | Yes |
| Shape in gain | Flat |
| Powe rating | 42.5 mW |
| Peak power detection | 156.987842 ps |

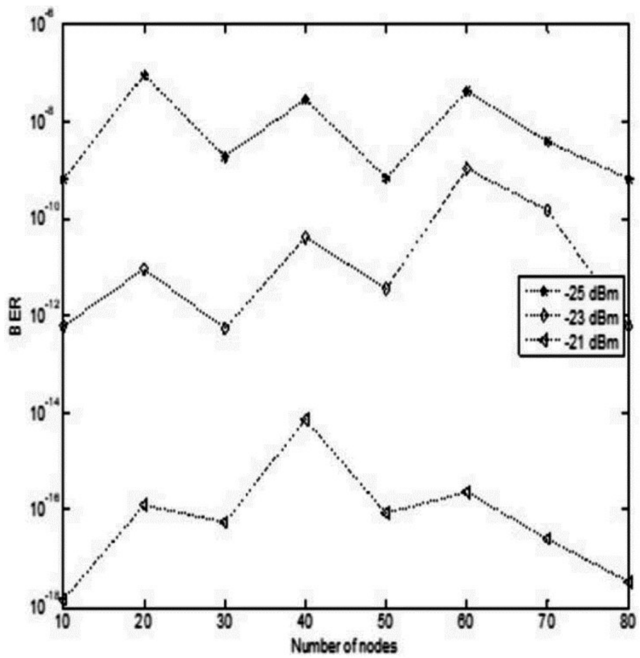


Fig. 5 — BER with respect to number of nodes

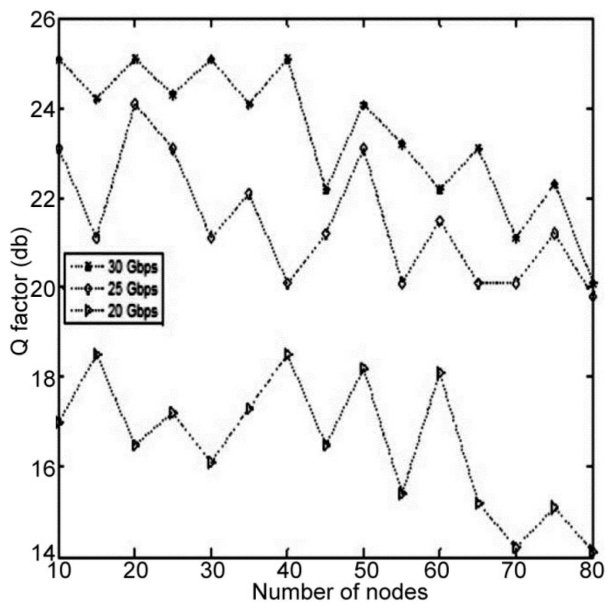


Fig. 6 — Q-factor with respect to number of nodes

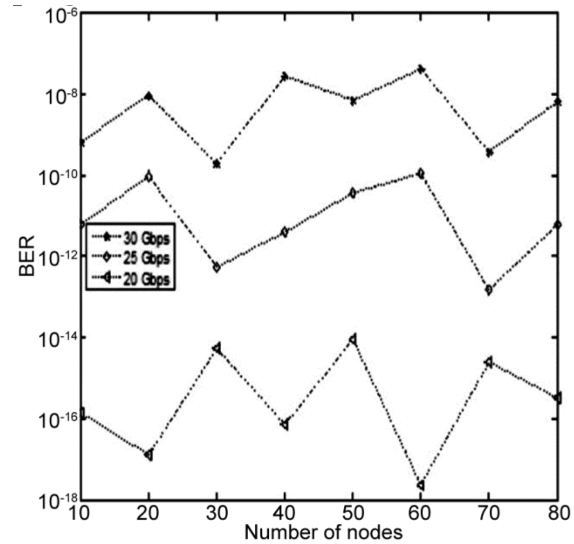


Fig. 7 — BER with respect to number of nodes

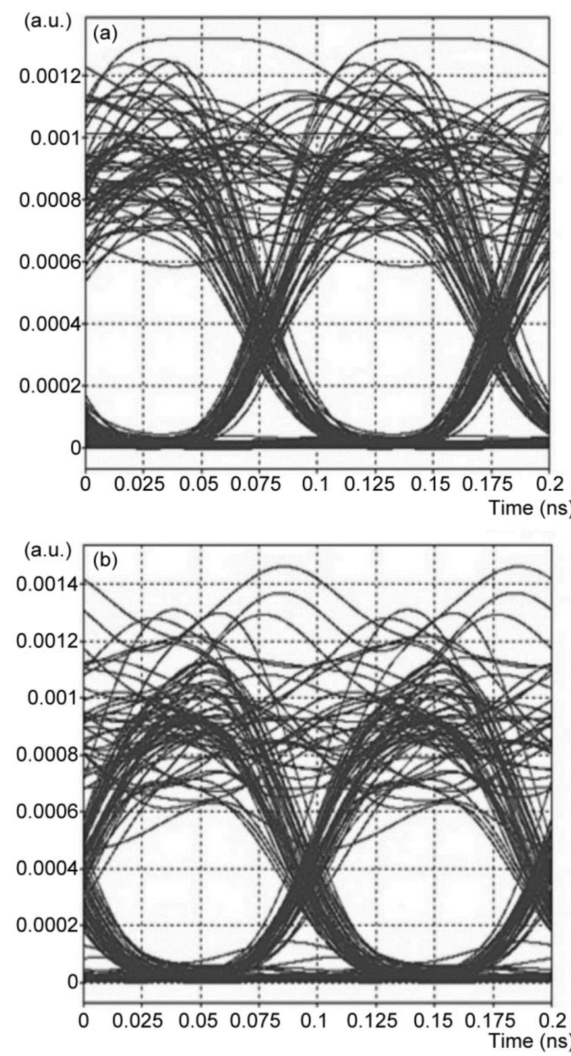


Fig. 8 — Eye diagram with 20 Gbps at 80 km for 500 users (a) at $10^{th}$ node (b) at $40^{th}$ node

that varations in transmission distance are shown the reflections in terms of induced fiber nonlinearity and internal crosstalk which further affected the signal strength.

Fig. 9(a,b) are analyzed for the same features with data rate of 25 Gbps with distance of 80 km. Effect of nonlineartity and crosstalk still maintained, which degraded the power level of transmitted optical signals.

Fig. 10(a) and 10(b) are also shown the acceptable outcome for the same features because effect of

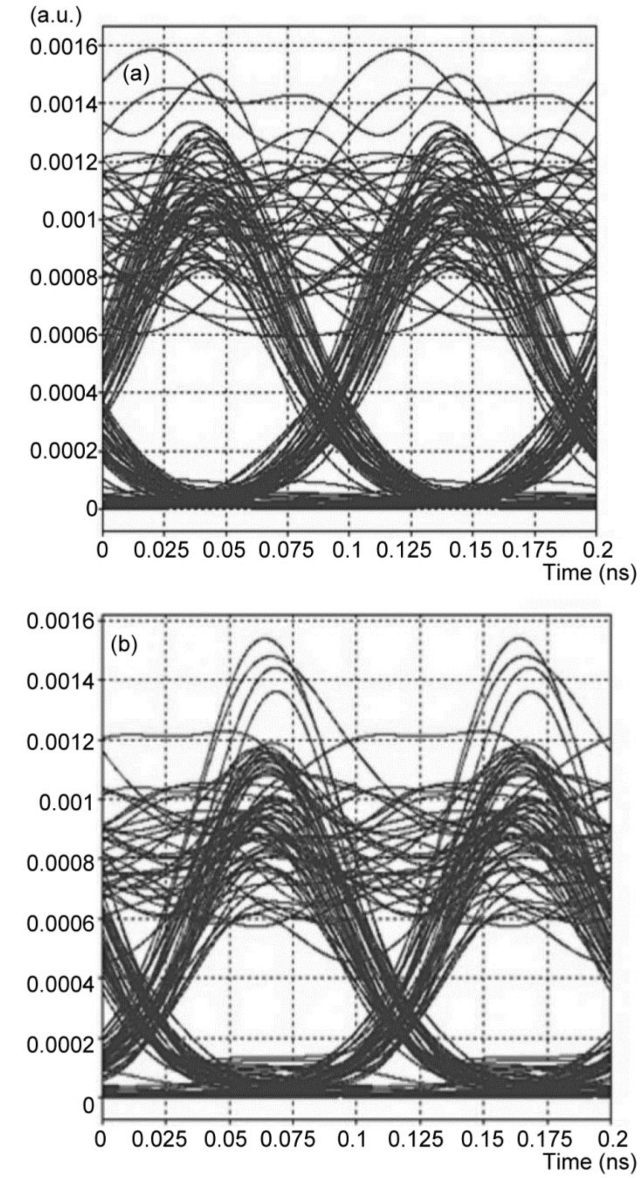


Fig. 9 — Eye diagram with 25 Gbps at 80 km for 500 users (a) at 10th node (b) at 40th node

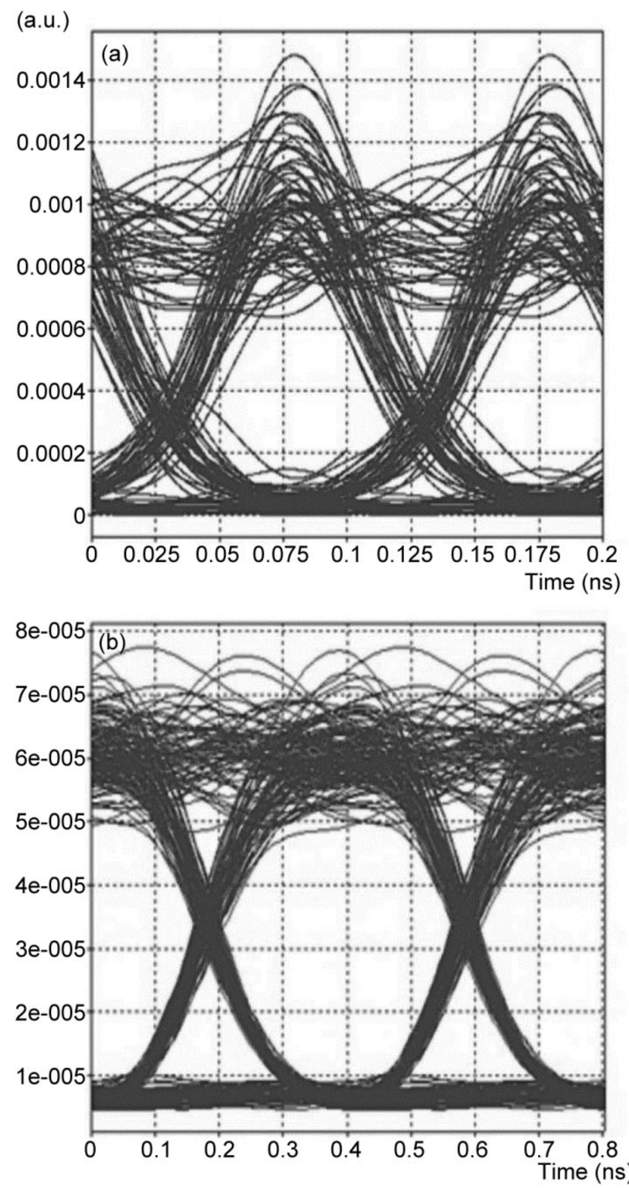


Fig. 10 — Eye diagram with 30 Gbps at 80 km for 500 users (a) at 10th node (b) 40th node

Table 3 — Analysis with the published research works

| Features | Wagnet et al. [11] | Singh et al. [12] | Singh et al. [13] | Kaur et al. [14] | Iannone et al. [15] | Kumar et al. [17] | Kumar et al. [18] | Present model |
|---|---|---|---|---|---|---|---|---|
| Bi-directional Ring | Yes | Yes | No | No | No | No | No | Yes |
| Cost of the system | High | High | High | High | High | High | High | Low |
| Booster | SOA | RAMAN | EDFA | RAMAN | EDFA | RAMAN | EDFA | RAMAN-EDFA |
| Channels | 20 | 30 | 10 | 20 | 20 | 200 | 160 | 500 |
| Transmission rate (Gbps) | 4 | 6 | 8 | 4 | 8 | 2 | 4 | 30 |
| Distance (Km) | 40 | 50 | 45 | 50 | 60 | 30 | 35 | 80 |
| Channel spacing (GHz) | 100 | 50 | 50 | 100 | 50 | 100 | 100 | 25 |

dispersion and nonlinearity are rectified by enhancing the input power and uniform power amplification from HOA.

## 5 Conclusion

Perforamance of super dense bi-directional line switched ring (SD-BLSR) system has been evaluated for 500 users with varying data rate of 30 Gbps, 25 Gbps and 20 Gbps with RAMAN-EDFA hybrid optical amplifier (HOA). Total transmission has set to 600 km with double span of 80 km. Acceptable results in terms of quality factor and bit error rate have recoarded at -25 dBm input power. Further, after analysis with the published works as shown in the Table 3, it has recommanded that this model is also capable to maintain the best rating for the same charactritics with the data rate of 30 Gbps.

## References

1 Yeh C H & Chi S, *IEEE Photon Tech Lett*, 19 (2007) 1139.
2 Sun X, Chan C K, Wang Z & Chen L K, *J Select Areas Commun*, 25 (2007) 18.
3 Joo Y, Lee G, Kim R, Park S, Song K, Koh J, Hwang S, Oh Y & Shim C, *IEEE Photon Technol Lett*, 16 (2004)6.
4 Kim C H, Lee C H & Chung Y C, *IEEE Photon Technol Lett*, 10 (1998) 1340.
5 Kim C H, Lee C H & Chung Y C, *IEEE Photon Technol Lett*, 10 (1998) 1118.
6 Fang X, Iraschko R & Sharma R, *J Light Technol*, 17 (1999) 1302.
7 Saengudomlert R, Modiano E & Gallager R G, *IEEE Trans Net*, 14 (2006) 330.
8 Iannone E, Sabella R, de Stefano L & Valeri F, *IEEE Trans Commun*, 44 (1996) 942.
9 Gustavsson M, Lagerstrom B, Thylen L, Janson M, Lundgren L, Morner A C, Rask M & Stoltz B, *Electron Lett*, 28 (1992) 2223.
10 Mahony M J O, *J Lightwave Tecnnol*, 6 (1988) 531.
11 Wagner S S, *IEEE Trans Commun*, 35 (1987) 419.
12 Singh S, *J. Opt Commun Netw*, 1 (2009) 313.
13 Singh S, Randhawa R, *Optik*, 120 (2009) 295.
14 Kaur G & Patterh M S, *Optik*. 124 (2013) 5366.
15 Iannone P P, *Optical Fiber Communication Conference and Exhibit 2001 (OFC 2001), Anaheim, California*, (2001), 3-1.
16 Iannone P P, Reichmann K C, Smiljanic A, N J, Frigo, A H Gnauck, Spiekman L H & Derosier R M, *IEEE J Lightwave Technol*, 18 (2000) 1955.
17 Kumar G & Kumar S, Photon *Netw Commun*, 39 (2020) 232.
18 Kumar G & Kumar S, *Nat Acad Sci Lett*, 44 (2021) 415.