Performance Analysis of Passive Optical Network incorporating Semiconductor Optical Amplifier and Fiber Bragg Gratings.

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Abstract: A reliable and cost effective hybrid wavelength/time division passive optical network is proposed by making system energy efficient with the employment of Fiber bragg gratings as well as semiconductor optical amplifier. Traffic load is managed with offering dual diverse bit rates to each optical network unit and system works on pay as you grow feature. Proposed system has potential to offer 80 Gbps of same bit rate in downstream and upstream. Four standbys of 1 Gbps each are also operational to provide additional bit rate when 10 Gbps is not required. Major accomplishment of proposed system is advantage to switch ON the required optical line terminal and keeping other in OFF state for making system energy efficient. SOA and FBGs have advantage of low cost and compact modules. Nonlinearities in SOA such as Four wave mixing generates upstream wavelengths from only providing downstream wavelengths. Uninterruptable services are capable to function even in the failure of any transmitter/receiver. Proposed system is scalable in bandwidth, network extensible to uphold next generation networks.

Keywords- Time division multiplexing, Wavelength division multiplexing, Fiber bragg gratings, semiconductor optical amplifier, Energy efficiency, Passive optical network, Arrayed waveguide grating, Optical distribution network.

1 Introduction

Bandwidth hungry applications and explosive increase in the demands lead to high energy consumption in optical networks. Now information and communication technology (ICT) is a consumer of approximately 10% of the total consumption of energy in industries [1]. Future requirements of energy are hard to get from natural energy sources. There are two different approaches to save the energy consumption in ICT (1) Installation of clouds and servers in remote locations (2) use deployed renewable energy sources to maximum extent [2]. Former mentioned approach is not ubiquitous because renewable energy cannot be obtained from any location or not present everywhere. Therefore, late mentioned approach is more favourable and challenging to scientists for efficiently using the available resources. Moreover, efficient use of renewable sources is also beneficial to reduce green house gases and reduce global warming [3]. In these days, high bandwidth per user is required typically 500 Mbps to 1 Gbps due to online games, telemedicine, file sharing, video conferencing etc. This huge bandwidth can be provided by deployment of passive optical networks and more specifically 10G PONs. Large number of users can be catered with PON networks and these saves substantial amount of energy. A noteworthy sum of energy can be saved with proper allocation of energy resources [5]. PONs have numerous benefits to offer high speed and low power consumption. PON basically consists of head end optical line terminal, optical distribution network and optical network unit [6]. Different power saving passive components are deployed such as arrayed waveguide gratings, passive splitters, sometime in flexible PONs switches can be used. Time division PONs were deployed to provide access to any user and used for Fiber to the home [7] [8]. But, in recent time, wavelength division multiplexing based PONs are prominent due to offering high bit rates. In WDM PONs, for accumulation and separation of signals, AWG is used and this makes the OLT and ONU dedicated [9]. These two aforementioned multiplexing PONs have their own advantages and disadvantages [10] [11]. TDM is more flexible than WDM but dedicated wavelengths are in WDM. But TDM PON is more efficient because one wavelength can serve al ONUs. Power splitting to multiple users can also introduces major losses of power in TDM but WDM offer high bit rates. Therefore, there is always trade off. In order to take advantages of both technologies, hybrid WD-TDM PON is a promising technology [12]. Different deployments of hybrid WDM-TDM PONs are given in [4], [8], [9], and [13–16]. Energy efficient hybrid WDM/TDM PON is proposed in [11] [17] but not efficient to resource utilization and high bit rates. Work in next generation PON for energy efficiency and cost effectiveness is required for future.

2 System Setup

Figure 1 depicts the system setup of proposed cost and energy efficient hybrid time/wavelength division passive optical network. Two types of transmitter are employed in the system such that symmetrical and asymmetrical. Four central office based transmitters, which further comprises of 4 channels in each are deployed as 10G transmitters for symmetrical PON. Also another, four 1G transmitters are incorporated in the system as asymmetrical data transmission for standby to provide extra speed and bandwidth to the system. 10G transmitters are termed as Tn,m where n is transmitter module number and m is frequency number inside module and 1G as T_{1G}. FBG modules are used after transmitters to reflect specific wavelength and in order to combine the signal, reflected spectrum in particular manner send to power combiner. At first combiner, frequencies 193.1 THz, 193.5 THz, 193.9 THz and 194.3 THz are accumulated. These frequencies are starting frequencies of each 10G transmitter. Similarly for power combiner 2, 3 and 4, frequencies are given as 193.2 THz, 193.6 THz, 194 THz, 194.4 THz, 193.3 THz, 193.7

THz, 194.1 THz, 193.4 THz, 193.8 THz, 194.2 THz, 194.6 THz respectively in the pairs of 4-4 frequencies. Standby transmitters to provide extra bandwidth to ONUs, 1G transmitter at 193 THz, 192.9 THz are also combined with 10G signals. Each power combiner is followed by a semiconductor optical amplifier for amplification as well as nonlinear phenomenon. Four wave mixing is exploited which generates extra frequencies from intended four carrier signals due to FWM. These additional signals are then used to lower the cost of system by using them as upstream carrier signals. Requirements of upstream wavelengths are eliminated inturn cost of lasers is saved by accomplishing nonlinear phenomenon. AWG 4 x 4 is receiving derive from four SOAs and provide diverse frequencies or wavelengths at each output port. Frequencies of 1st and 4th ports are consisting of 8 Frequencies which are similar and having Frequencies 193.1 THz, 193.3 THz, 193.5 THz, 193.7 THz, 193.9 THz, 194.1 THz, 194.3 THz, 193.5 THz and also two 1G frequencies 193 THz and 192.9 THz. Port second and third of AWG have wavelengths 193.2 THz, 193.4 THz, 193.6 THz, 193.8 THz, 194 THz, 194.2 THz, 194.4 THz, 194.6 THz and 1G wavelengths. Frequencies of AWG's first and third port are fed to single mode fiber of 20 km and second, third port frequencies are also fed to SMF of 20 km but at different ODN. After transmission, specific FBGs are placed to receive particular wavelength as mentioned in the transmitter side. Power splitter of 32 ports catered the 32 users each ONU. Carrier from four wave mixing are taken and filtered by FBGs for upstream followed by 20 km SMF and receiver.

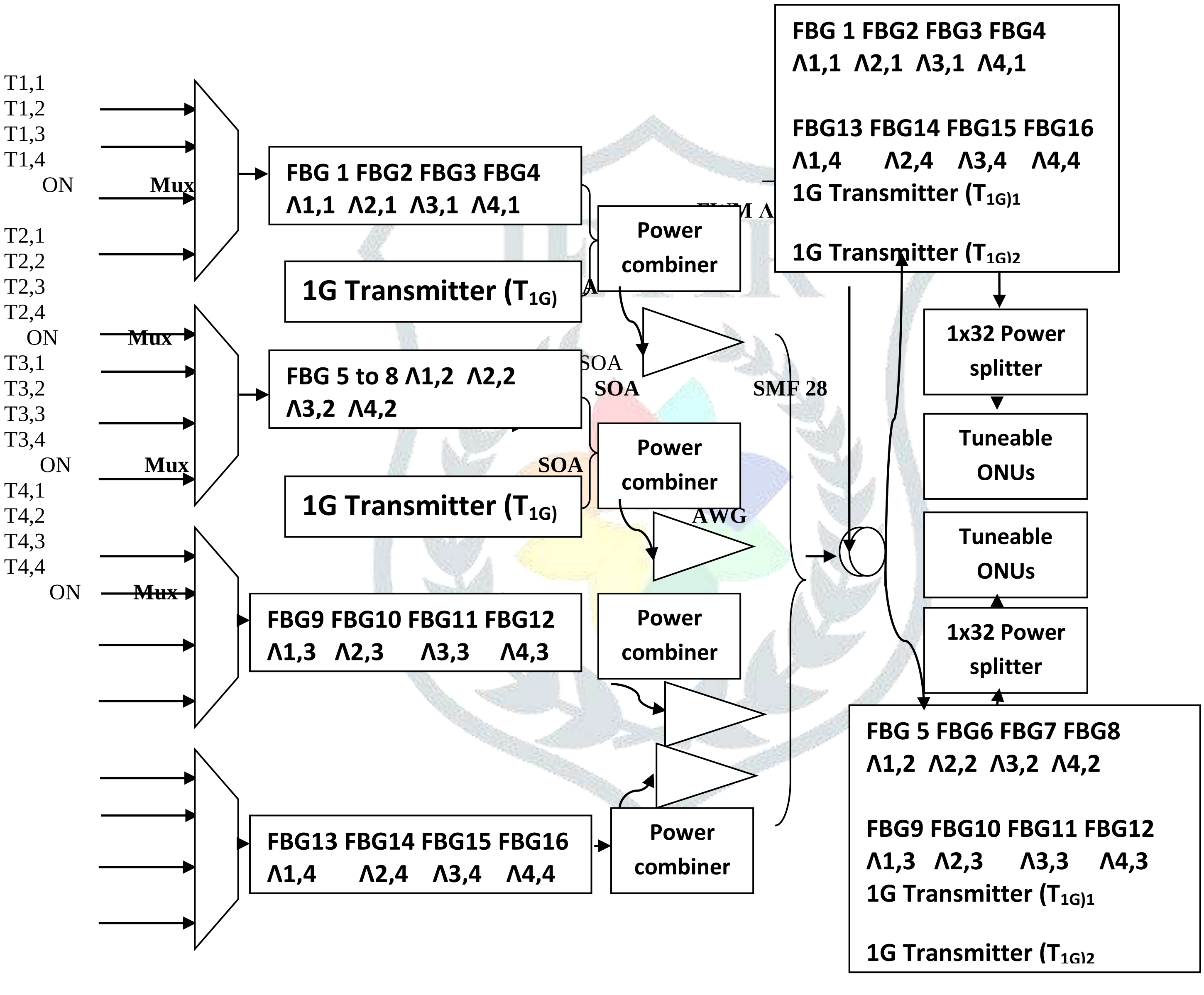


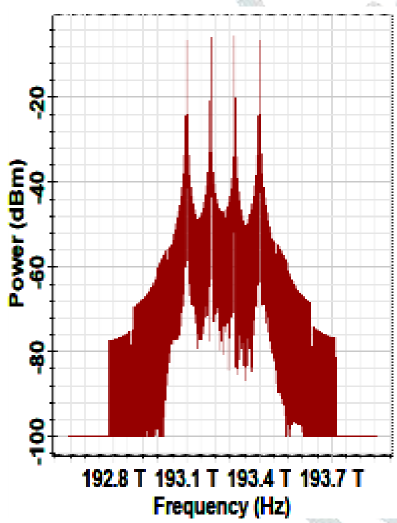
Figure 1 Proposed hybrid TDM/WDM PON with cost and energy efficiency

Principle of operation

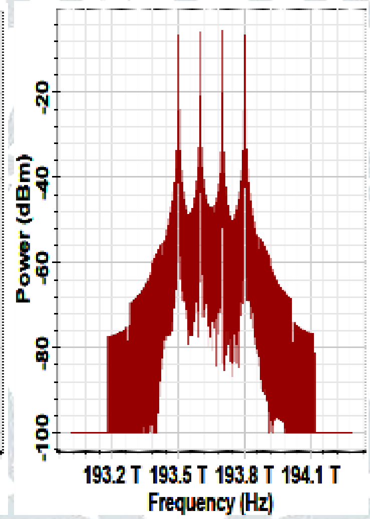
As depicted in the Figure 1, proposed time/wavelength division multiplexing is based on efficient use of resources located in central office. Frequencies of 10G transmitters are combined separately in the pairs of 4-4 with the help of FBGs as given in section 2. Each wavelength carry 10G data rate and fed to semiconductor optical amplifier. Due to power of 5 channels, FWM emerges in SOA and extra frequencies are generated. AWG's 1st and 4th port consists of 8 10G wavelengths and two 1G wavelengths. Similarly, AWG's port 2nd and 3rd are processed. Therefore, it is noteworthy that each optical distribution network and optical network unit get one wavelength from each transmitter unit or 2 wavelengths from each Tx module. For example, maximum frequencies of transmitter module 1 are to be used 193.1THz and 193.3 THz, for transmitter module 2 are 193.5 THz and 193.7 THz, for transmitter module 3 are 193.9 THz, 194.1 THz, for transmitter 4 are 194.3 THz and 194.5 THz. These eight frequencies also consist of two 1G signals. Hence each ODN is capable to support 80 Gbps simultaneous data rate (from eight 10G transmitters) and 2 Gbps from 1G transmitter. Frequencies are passed through 20 km optical fiber (SMF-28) and at user end, FBGs are placed to detect particular frequency. To support 32 users, power splitter of 1 x 32 is employed. Each optical network unit (ONU) receives 8 wavelengths and tuned to specific wavelength at which data speed is needed. In case of the increases in the demand of bandwidth and high bit rate, ONU is assigned a new frequency out of 8 frequencies and so on unless speed requirements are upto 80 Gbps. For example, when data requirement is of additional 1 Gbps in 10G link, another 10G wavelength is not assigned. However, a 1 G transmitter's wavelengths are assigned to the system in order to save the bandwidth as well as energy of operation. This function of ON and OFF for transmitter is performed by medium access control at optical line terminal. Four wave mixing in SOA is providing cost efficient operation by generating additional wavelengths from intended carriers in order to accomplish upstream transmission without the use of extra wavelengths/Laser sources. Moreover, FBGs and SOAs are cheap, small size and monolithically integrated components which does not increase the complexity of the system. Proposed system is flexible and reliable to use because if any transmitter unit fails or not working properly, another available wavelength of different transmitter replace this. Thus, proposed system can extend bandwidth, data rate, reliability of operation, cost effectiveness and energy efficiency.

Results and Discussions

For the realization of the proposed energy efficient hybrid time/wavelength division multiplexing, a simulation suit Optiwave Optisystem is used this work. Optical spectrums of each frequency carrier are depicted in the Figure 2. OSA analyzer is basically a depicter to represent the power of each carrier and centre frequency of the carriers. This is essential to check the signal availability in the network. Optical spectrums of each transmitter modules are given in Figure 2 (a), (b), (c), (d). Module 1 and wavelengths of 4 internal transmitter of module 1 are shown in Figure 2 (a) and similarly rest of the depiction represent module 2, module 3 and module 4 carriers. Starting frequency of module 1 is 193.1 THz and rest three frequencies are at spacing of 100 GHz. Module 2, module 3 and module 4 has starting frequencies of 193.5 THz, 193.9 THz, and 194.3 THz respectively with 100 GHz frequency spacing. Figure 2 (e) (f) (g) (h) depicts the optical spectrums of carriers after operation of FBGs and power combiner for assigning different frequencies to the signal and these frequencies are consisting of wavelength of each 10G transmitter with 1G wavelengths. Figure 2 (i) (j) (k) (l) represents the optical spectrum of carrier signals of each power combiner after Four wave mixing i.e. after semiconductor optical amplifier and it is evident that after SOA, number of carriers are increases due to more side peaks of FWM which will be used for upstream.



(a)



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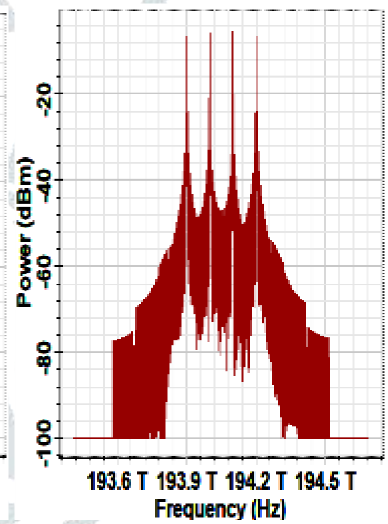

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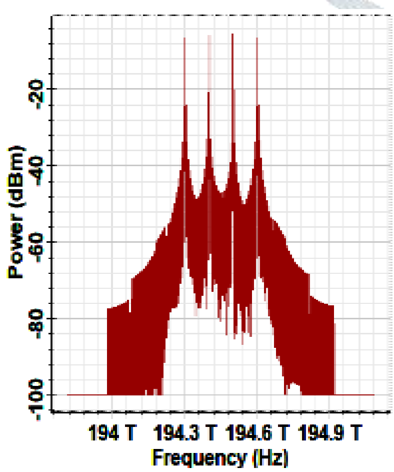

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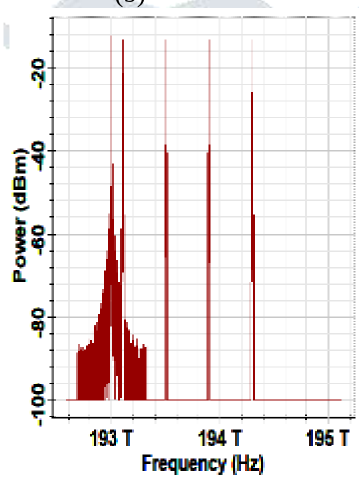
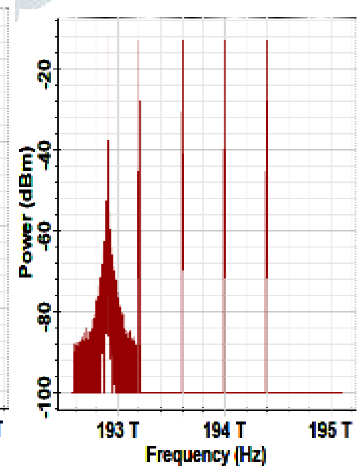
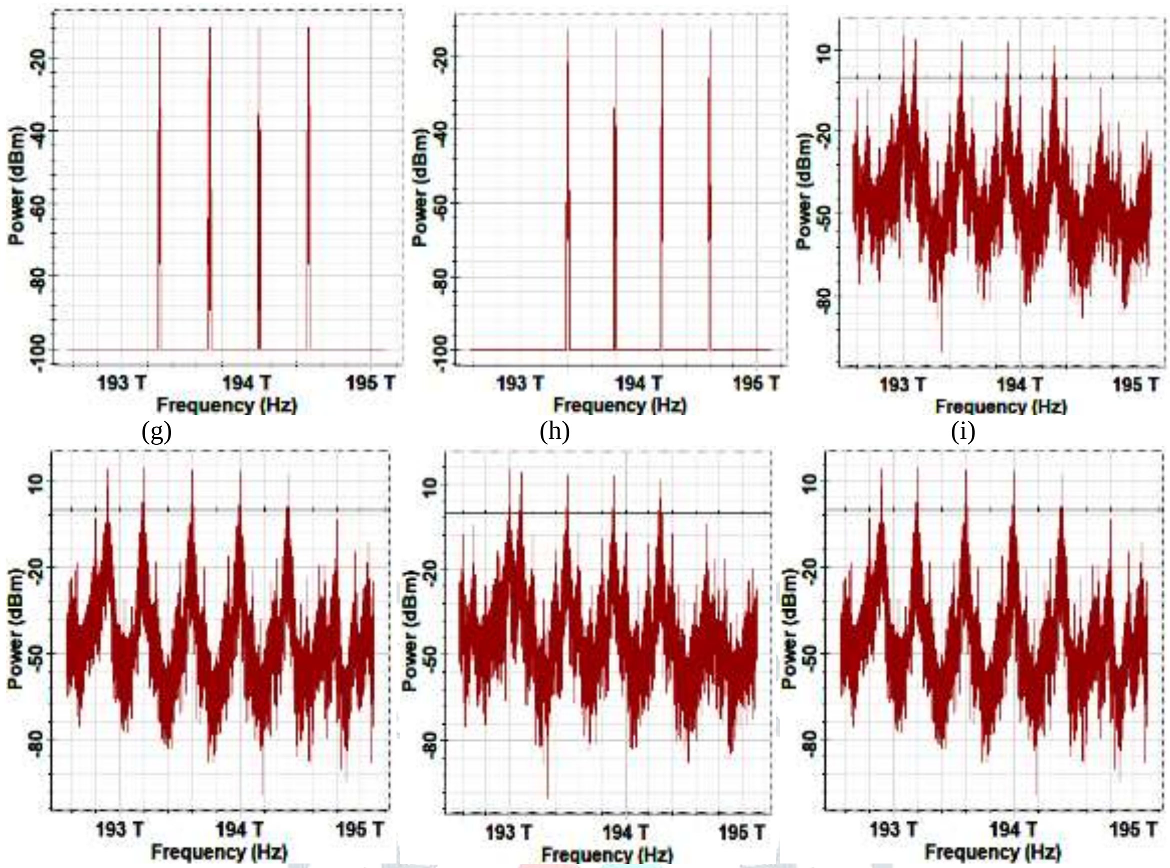


(e)



(f)

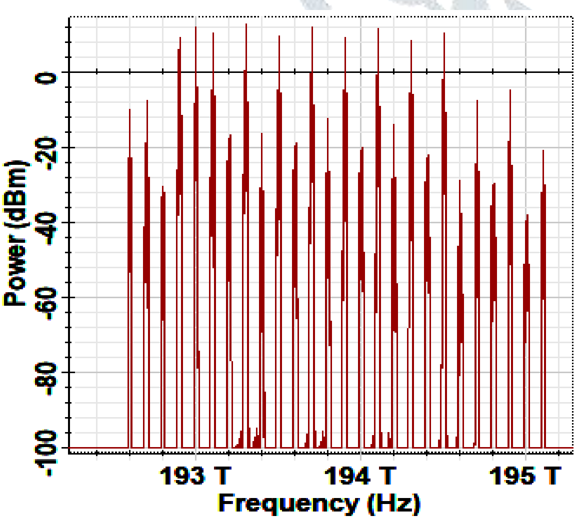


(g) (h) (i)

(j) (k) (l)

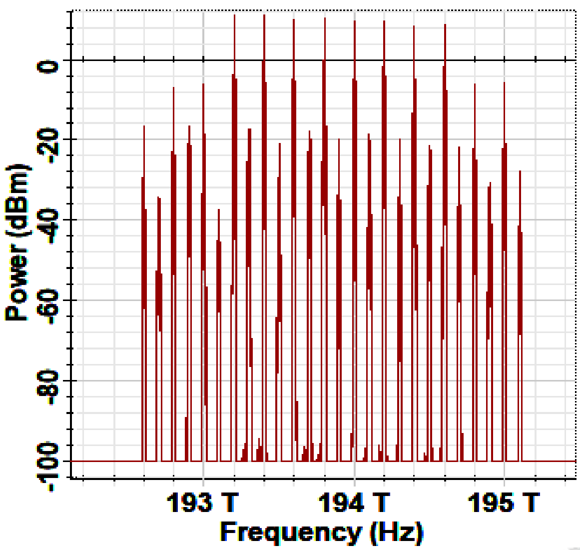
Figure 2 Optical spectrums of carrier signals of (a) module 1 (b) module 2 (c) module 3 (d) module 4 (e) after FBGs 1,2,3,4 (f) FBGs 5,6,7,8 (g) FBGs 9,10,11,12 (h) FBGs 13,14,15,16 (i) after FBGs 1,2,3,4 SOA (j) after FBGs 5,6,7,8 SOA (k) after FBGs 9,10,11,12 SOA (l) after FBGs 13,14,15,16 SOA

After semiconductor optical amplifier, signals are communicated to array waveguide gratings and output ports optical spectrums with WDM analyzer's outputs are depicted in Figure 3. Figure 3 (a) (b) represents the OSA output and WDM analyzer's output respectively in case of output of AWG port 1 and 4, because same frequencies emerges at both the output ports of AWG and similarly, Figure 3 (c) (d) depicts OSA output and WDM analyzer's output respectively in case of output of AWG port 2 and 3, because same frequencies emerges at both the output ports of AWG.



Frequency (THz)	Signal Power (dBm)	Noise Power (dBm)	OSNR (dB)
192.9	20.45053	-95.804217	116.25475
193	20.937191	-97.114441	118.05163
193.1	14.829064	-97.892639	112.7217
193.2	-7.4352397	-92.57833	85.143091
193.3	16.516126	-90.523544	107.03967
193.4	-9.3742571	-93.177671	83.803414
193.5	14.391091	-97.211678	111.60277
193.6	-9.324428	-93.807889	84.483461
193.7	15.72134	-91.76401	107.48535
193.8	-6.3758849	-94.21866	87.842775
193.9	14.002884	-97.573081	111.57597
194	-10.25333	-94.386311	84.132982
194.1	15.2628	-92.397058	107.65986
194.2	-7.7589794	-94.79116	87.03218
194.3	13.09512	-98.053701	111.14882
194.4	-12.470342	-95.63814	83.167798
194.5	14.126649	-93.836063	107.96271
194.6	-21.581665	-96.261487	74.679822

(a) (b)



(c)

Frequency (THz)	Signal Power (dBm)	Noise Power (dBm)	OSNR (dB)
192.9	-4.073679	-95.804165	91.730486
193	-0.6399623	-97.114453	96.47449
193.1	-26.69052	-97.892843	71.202323
193.2	15.300072	-92.578318	107.87839
193.3	-7.4947357	-90.523557	83.028821
193.4	16.021522	-93.177662	109.19918
193.5	-14.902973	-97.211701	82.308728
193.6	14.437999	-93.807899	108.2459
193.7	-9.105766	-91.764027	82.658261
193.8	15.09922	-94.218657	109.31788
193.9	-12.983009	-97.573116	84.590106
194	14.021152	-94.386304	108.40746
194.1	-9.9823701	-92.397058	82.414688
194.2	14.655532	-94.791159	109.44669
194.3	-12.505943	-98.053666	85.547722
194.4	13.077806	-95.638151	108.71596
194.5	-12.288265	-93.836073	81.547808
194.6	13.661274	-96.261508	109.92278

(d)

Figure 3 Optical spectrum and WDM carriers of (a) (b) 1st and 4th port of AWG (c) (d) 2nd and 3rd port of AWG respectively

Figure 4 illustrates the performance of the system when 40 Gbps is delivered to the optical network units and it is evident that as the distance prolongs, there is significant degradation in the performance of the system. Amplitude degrading factor, pulse width broadening, nonlinear effects are the main cause of degradation. Q factor of the system is evaluated at diverse link lengths from 10 km to 40 km and it is perceived that system works for 40 km within acceptable range of Q as fixed by international telecommunication union. Results are observed at ONU of 1st and 4th port of AWG's wavelengths at upper 32 ONUs and for wavelengths of 2nd as well as 3rd AWG's ports wavelengths at 32 ONUs. Results reveal that wavelengths of former mentioned case perform better than later mentioned wavelengths. Quality factor with respect to different distance is given in Table 1.

Table 1 Values of Q factor at different distances

Distance (km)	1st and 4th AWG's port wavelengths	2nd and 3rd AWG's port wavelengths
10	16.49	15.88
20	15.04	13.66
30	9.52	7.91
40	7.36	5.9
50	2.53	2.35

Table 2 Values of BER at different distances

Distance (km)	1st and 4th AWG's port wavelengths	2nd and 3rd AWG's port wavelengths
10	10^{-61}	10^{-57}
20	10^{-51}	10^{-43}
30	10^{-22}	10^{-15}
40	10^{-14}	10^{-9}
50	10^{-3}	10^{-3}

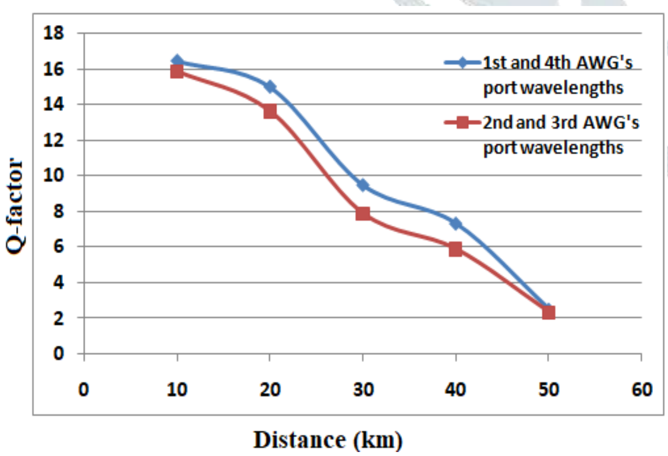


Figure 4 Performance of Proposed system at diverse distances in terms of Q factor

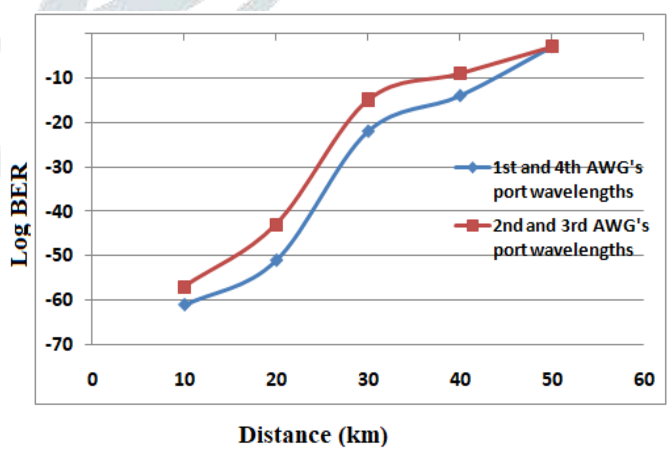


Figure 5 Log BER versus transmission distance

Figure 5 depicts the performance of the system when 40 Gbps is delivered to the optical network units and it is observed that as the distance increase, there is increase in bit error rate. Log BER of the system is evaluated at diverse link lengths from 10 km to 40 km and it is perceived that system works for 40 km within acceptable range of BER i.e. 10^{-9} as fixed by international telecommunication union. Results are observed at ONU of 1st and 4th port of AWG's wavelengths at upper 32 ONUs and for wavelengths of 2nd as well as 3rd AWG's ports wavelengths at 32 ONUs. Results reveal that wavelengths of former mentioned case perform better than later mentioned wavelengths. BER with different distances are given in Table 2. Figure 6 represents the performance of downstream and upstream of the proposed hybrid wavelength and time division multiplexing passive optical network. Downstream signals are from optical line terminal to optical network unit via optical distribution network which consists of optical fiber. Link length is varied to check the Q factor of the system in upstream and downstream. It is perceived that Q factor of the downstream is more as compared to upstream signals due to better maintenance of OLTs at central office. Moreover, upstream wavelengths are generated from semiconductor optical amplifier with four wave mixing emergences but even though they are in acceptable range at 30 km in upstream.

Table 3 Values of Q factor in downstream and upstream at different distances

Distance (km)	Downstream	Upstream
10	16.49	15.24
20	15.04	12.56
30	9.52	6.99
40	7.36	5.09
50	2.53	2.2

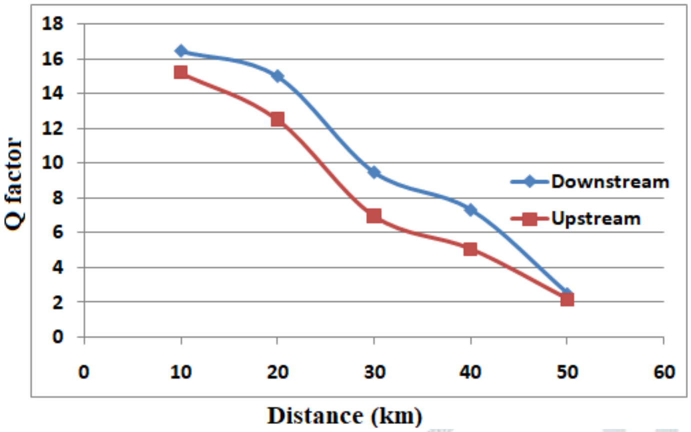
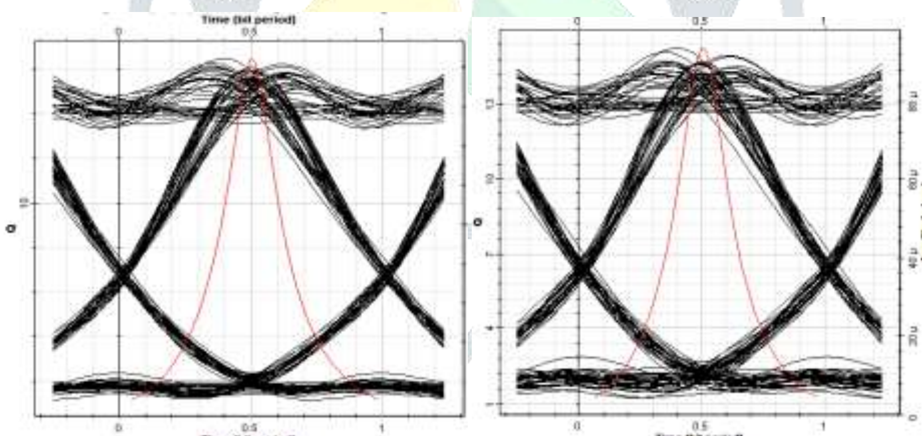


Figure 6 Distance versus Q factor for downstream and upstream

Figure 7 depicts the Eye diagram of the energy efficient hybrid WDM/TDM passive optical network. It is a decision component which provides Q factor and BER of the system with values of eye opening as well as closure. It is noteworthy that more Q will be, if eye opening is wide open and jitter is less. Figure 6 (a) depicts the Eye diagram of downstream and Figure 6 (b) depicts the Eye diagram of upstream. It is clear that Eye opening is more in case of downstream and less in upstream.

Table 4 represents the switching ON and OFF of different transmitters to provide pay as you grow services. Figure 8 depicts the power consumption according to traffic load on the system. Comparison is made between conventional scheme when all the modules kept all the time in ON state and proposed scheme where modules are kept ON/OFF according to load. It is observed that proposed scheme is energy efficient and ON/OFF module as load increase.



(a) (b)

Figure 7 Eye diagrams of hybrid WDM/TDM PON for (a) Downstream (b) Upstream

Table 4 Traffic Load management of pay as you grow services

ODN	Load	Module1	Module2	Module3	Module4
ODN1	Load < 10G	ON($\lambda_{1,1}$)	OFF	OFF	OFF
	10 < Load < 20	ON($\lambda_{1,1}$)	ON($\lambda_{2,4}$)	OFF	OFF
	20 < Load < 30	ON($\lambda_{1,1}$)	ON($\lambda_{2,4}$)	ON($\lambda_{3,3}$)	OFF
	30 < Load < 40	ON($\lambda_{1,1}$)	ON($\lambda_{2,4}$)	ON($\lambda_{3,3}$)	ON($\lambda_{4,2}$)
ODN2	Load < 10G	ON($\lambda_{1,2}$)	OFF	OFF	OFF
	10 < Load < 20	ON($\lambda_{1,2}$)	ON($\lambda_{2,1}$)	OFF	OFF
	20 < Load < 30	ON($\lambda_{1,2}$)	ON($\lambda_{2,1}$)	ON($\lambda_{3,4}$)	OFF
	30 < Load < 40	ON($\lambda_{1,2}$)	ON($\lambda_{2,1}$)	ON($\lambda_{3,4}$)	ON($\lambda_{4,3}$)
ODN3	Load < 10G	ON($\lambda_{1,3}$)	OFF	OFF	OFF
	10 < Load < 20	ON($\lambda_{1,3}$)	ON($\lambda_{2,2}$)	OFF	OFF
	20 < Load < 30	ON($\lambda_{1,3}$)	ON($\lambda_{2,2}$)	ON($\lambda_{3,1}$)	OFF
	30 < Load < 40	ON($\lambda_{1,3}$)	ON($\lambda_{2,2}$)	ON($\lambda_{3,1}$)	ON($\lambda_{4,4}$)
ODN4	Load < 10G	ON($\lambda_{1,4}$)	OFF	OFF	OFF
	10 < Load < 20	ON($\lambda_{1,4}$)	ON($\lambda_{2,3}$)	OFF	OFF
	20 < Load < 30	ON($\lambda_{1,4}$)	ON($\lambda_{2,3}$)	ON($\lambda_{3,2}$)	OFF
	30 < Load < 40	ON($\lambda_{1,4}$)	ON($\lambda_{2,3}$)	ON($\lambda_{3,2}$)	ON($\lambda_{4,1}$)

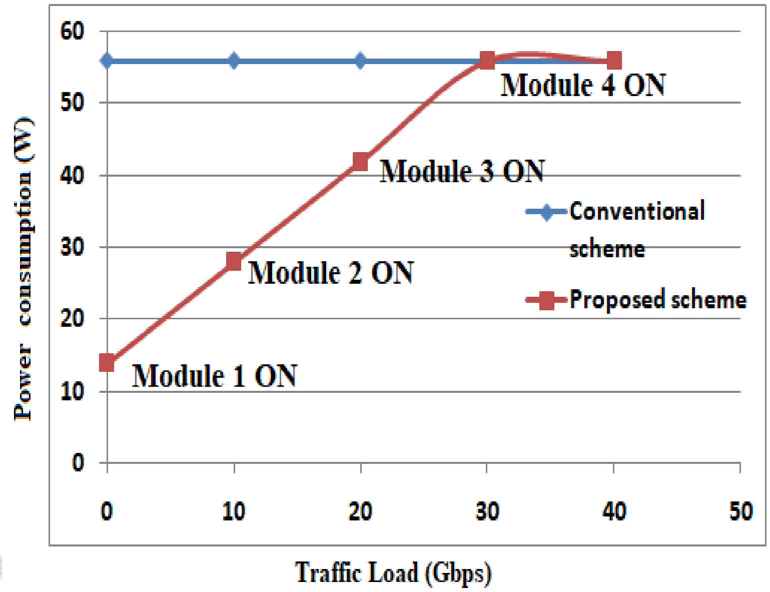


Figure 8 Comparison of conventional and proposed scheme for energy efficiency in hybrid WDM/TDM PON

Conclusion

In this work, a cost effective hybrid wavelength/time division passive optical network with energy efficiency is proposed with the incorporation of compact, low cost Fiber bragg gratings. Semiconductor optical amplifier is used to further lower the cost by utilizing Four wave mixing generated wavelengths for upstream which eliminate the cost of upstream lasers. Traffic load is managed with offering dual diverse bit rates such as 10G and 1G to each optical network unit and system works on pay as you grow feature. Proposed system has potential to offer total 160 Gbps in downstream and 80 Gbps of same bit rate to ONUs. Four standbys of 1 Gbps each are also operational to provide additional bit rate when 10 Gbps is not required. Major accomplishment of proposed system is advantage to switch ON the required optical line terminal and keeping other in OFF state for making system energy efficient. Uninterruptable services are capable to function even in the failure of any transmitter/receiver. Result reveals that performance of downstream is better than upstream and works for 40 km and 30 km respectively. Further, comparison of conventional and proposed scheme for energy efficiency are compared and revealed that proposed scheme is efficient to save power.

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