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Spectrum Utilization with Increasing Traffic, Based on ILP Model in Elastic Optical Networks

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Abstract: ***The traffic volume due to bandwidth hungry multimedia and internet applications is growing exponentially and demands a significant change in communication networks. Due to the high speed communication requirements present researchers are giving interest in efficient, adaptive and cost effective optical network design. Recent works in optical networking using optical fiber communication focusing on the efficient utilization of resources by flexibly utilizing the spectrum and adaptive networking to support a better quality of service (QoS). The flexible grid in optical spectrum and adaptive optical networking save spectrum with improvement in energy and spectral efficiency. Simple modulation of a signal can support lower bit rate transmissions, which are more sophisticated for higher bit rates. Recent advances on hardware such as optical transponders and switches make it more feasible to develop a new elastic-optical networking (EON) paradigm. Current research efforts are on new innovations of optical transponders and optical switches to support EON functionalities. The measure of spectrum utilization factor with respect to the value of traffic requirement increases the flexibility of the networks. The Integer Linear Programming (ILP) is used to extract the optimal solution for analysis of utilized frequency slots with available slots and increased traffic in the network. This framework also calculates the spectrum utilization for different traffic in order to choose required frequency slot for the EON to provide uninterrupted network service.***

Keywords: ***BVT, EONs, Flexi grid, ILP, Optical networks, Spectrum Utilization.***

I. INTRODUCTION

To provide better Quality of Service to a communication client, it is required to have a high speed network which handles the large variety of network traffic demands. Current optical networks uses wavelength division multiplexing (WDM) technology for communication over a constant(fixed) value of the frequency grid [1]. The growth of traffic volume can be efficiently controlled by the introduction of flexi grid technology. Elastic optical networks (EONs) support flexible central frequency and adaptive spectrum utilization in optical networking. The wastage of the optical spectrum due to conventional ITU fixed grid can now replace to mini-grid, which improves the spectrum utilization to fulfill the data traffic demand and support desire quality of service beyond the 100-Gb/s era [2-3]. Exiting optical networks employ a single modulation format at single or multiple rates, which are rigid in nature. Fig.1 shows the exiting fixed frequency grid of ITU and flexible grid.The Fixed grid doesn't support a high bit rate as it causes overlap of grid boundary. As shown in figure 10 Gigabits per second, 40 Gigabits per second (Gb/s) and 100 Gigabits per second rates are supported by the existing fixed grid. In flexible grid the channel spacing is not fixed, which allows a higher bit rate over 100 Gb/s and efficiently utilizes the spectrum to increase spectral efficiency.

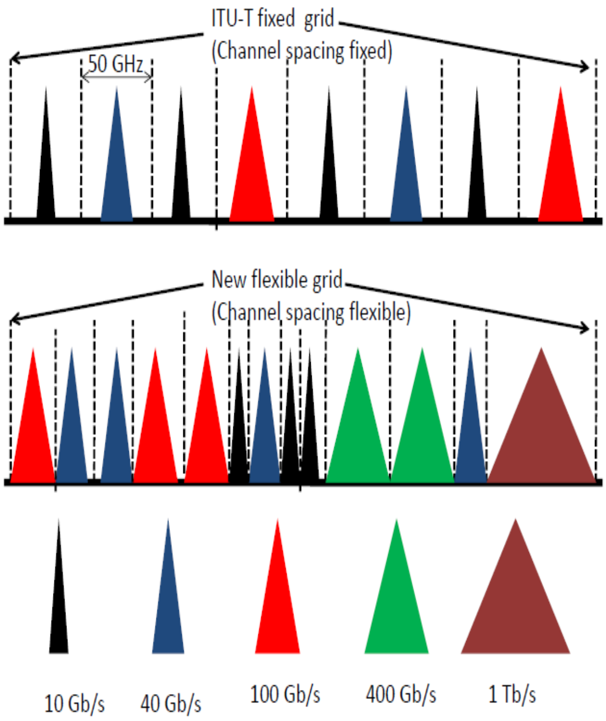

Fig.1. Spectrum width of different bit rates (ITU-T grid).

Digital signal processing (DSP) with coherent detection in optical communication has opened a different ways to utilize Nyquist wavelength division multiplexing (WDM) to achieve better spectral efficiency [4]. This kind of technology with conventional 50 GHz ITU-T frequency grid can support 100 Gigabits per second dense wavelength division multiplexing communication system [3]. The dense-WDM is the advanced technology used in optical communication over WDM.

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The forthcoming optical transport networks required high capacity per fiber to fulfill the increasing demand of the traffic, high capacity per optical channel and satisfy economically.

DSP is currently integrated with all the advanced communication process. Due to the introduction of DSP in the transceiver design, multicarrier modulation is realized. This multicarrier modulation supports the efficient utilization of the spectrum-band and efficient utilization of the network. In optical, the frequency division multiplexing also called orthogonal frequency division multiplexing (OFDM) orthogonally modulates the frequency spectrum of adjacent subcarrier channels, which boost the communication spectral efficiency. Similarly, Nyquist wavelength division multiplexing (NyWDM) is one of them. Liquid crystal on silicon (LCoS) is now a days most effectively using in switch design. Bandwidth variable spectral routing can be achieved using (LCoS) based wavelength selective switches (WSSs). A higher-order modulation format with advanced software is now possible by using DSP with an in-phase modulator and quadrature-phase (IQ) modulator. IQ is an integral part of modern modulation techniques. Another advanced circuit such as photonic integrated circuits (PICs) combines and integrates more than one number of optical components (discrete) on a single chip [5]. This will reduce the complexity of multicarrier simultaneously reduce the value and issue of the multicarrier superchannels to change the center frequency flexibly and enhances the capacity of the optical networks. This technological advances change the fixed optical network architecture to flexible with respect to optical reach. Due to the initiation of the flexible optical networking, it is possible to fulfill the traffic demand elastically and is called spectrum sliced elastics optical networks (SLICE) [2, 6, 7] and is presently called elastic optical network (EON) [8, 1]. The EON in the optical domain efficiently controls the traffic and increases the spectrum efficiency of the communication networks.

In EONs bandwidth variable reconfigurable optical add-drop multiplexers (ROADMs) route the multiwavelength-based superchannel with a minimum spectrum. On hardware side bandwidth variable optical transponder and without grid (grid-less) wavelength selective switch(WSS) are the advanced technologies utilized by the elastic optical networks architecture. This helps in improving the node designs in optical networking to solve the traffic demand of the near future.

This paper reviews the EON architecture, building blocks, technologies and propose a spectrum utilisatio model which advance the old technology to meet the recent traffic demands. In the next section, the network architecture and enabling technologies for EONs are explained. The ILP mode and problem formulation is presented in section III. The results are explained in section IV. At the end this paper is summarized by Section V.

II. EONS ARCHITECTURES AND TECHNOLOGIES

The diagram shown in Fig.2 is the architecture and different component used in the network, which is having two layers, the innermost optical core layer and outermost electronic outer layer [9]. The elastic optical core layer uses different optical advanced technologies like bandwidth variable transponders (BVTs) and bandwidth variable optical crossconnect (BV-OXC) also called flexible wavelength selective switch (WSSs).

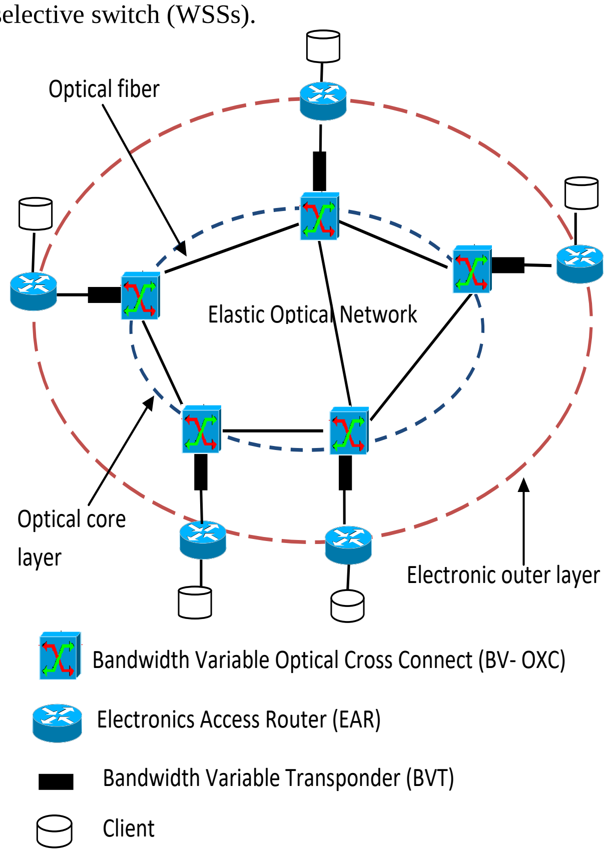

Fig. 2.Elastic Optical Networks Architecture.

A. Bandwidth Variable Transponders

Emerging technologies on multicarrier modulation support to generate a multi-variety of superchannels from a single type of transponder [3]. The advanced modulation format allows to adjusting of the symbol rate, bit rate, and subcarriers. Due to this option, transponders are designed to reduce the spectrum occupying capacity and improve the spectrum resource in the networks [10]. Modulation format includes adjustment of bit rate and symbol rate to get an adaptive spectral occupancy to increase the channel capacity.

By adjusting the modulation format for different distances and bit rates of transmission, the bandwidth can be tuned. For example, like BPSK and QPSK are considered as less spectrum efficient modulation technique used for high distance transmission. The sliceable bandwidth variable transponder as a slice concept, can handle multiple modulation formats, multiple symbol bit rates, slicing of the spectrum to increase the adaptability. It improved the flexibility by allocating the capacity into more number of optical paths which are transmitted to its destination.

Fig.3 shows the working of sliceable Bandwidth Variable Transponders, which is more flexible than single bandwidth variable transponders. According to the traffic, the sliceable-BVT split the bandwidth and allows it to increase the path for other data. Due to this sliceable capability, it increases the flexibility of the network.

The advanced multiplexer called, ROADM which dynamically add or drop of wavelengths. ROADM is part of the network node, which allows dynamic dropping and adding of wavelength in the node of a network. In the past, DWDM signal wavelengths were transmitted through a constant 50 or 100 GHz bandwidth ITU grid. The disadvantage of fixed channel bandwidth are overcome by the Flexi-grid ROADM, which allow the additional advantage of add and drop of wavelength in optical the domain.

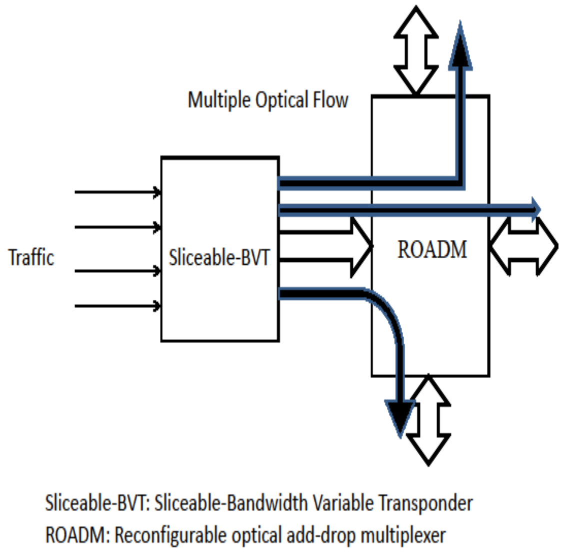

Fig. 3. Working of Sliceable-BVT

B. Wavelength Selective Switches (WSS)

The wavelength selective switches also called flexible spectrum selective switches can multiplex and switch variable spectral bands [1]. The recent WSSs technologies are based on the liquid crystals on silicon (LICoS), optical microelectromechanical systems (MEMS), or silica planar lightwave circuits (PLCs) [11].MEMS mirror based switch has an array of mirrors with an independent tilt facility. Each incident beam reflected based on the angle and placed the image on the output fiber material. The aperture function of a mirror and the transfer function of the optical device decide the field spectrum of WSS [12]. The reconfigurable optical add-drop multiplexer (ROADM) with WSS can enhance the spectral efficiency by adjusting their spectral width. All this can be achieved by LCoS light modulators based bandwidth variable WSSs.

Using LCoS it is possible to control the phase of the reflected light beams and by managing the number of pixel columns the width of the passband can be modified [3]. A monolithic photonic integrated circuit (PIC) wavelength selective switch has been explained, which resolve the requirement of large volumes in free space technologies [13].

C. Nyquist WDM and Superchannels

In optical networking Nyquist pulse coding of the optical signal is the most efficient modulation techniques and WDM is the promising technique for efficient high spectrum capacity communication [15]. A superchannel is a combination of optical signals modulated and multiplexed together with huge spectrum utilisation. Nyquist WDM supports superchannel multiplexing of sub-channels in the optical frequency domain nearer to the symbol rate [3]. By varying the bit per symbol for each sub-channel it is possible to fulfill the traffic demand by adjusting the line rate beyond 100 Gb/s.

D. Adaptive Spectrum Allocations

In the elastic optical networks, the communication spectrum which is optical in nature and the entire optical spectrum are flexibly divided to adaptively allocate the optical channel based on traffic demands and transmission distance [14]. Due to this adaptability, optical channels are efficiently used spectrum with less guard band. This path with variable bit rates can generate elastic optical paths by the transceivers.

E. Distance Adaptive Spectrum Allocation

Different high order modulation techniques with higher spectrum utilization efficiency will save the spectrum of the network for a short optical path. In distance adaption, the minimum necessary spectrum resource according to demand is adaptively allocated across an optical route. The optical fiber resources are determined based on the knowledge of optical fiber width and the modulation technique. The digital modulation technique allows generating and detecting optical signals with different modulation formats with a particular type of transceiver. Nyquist WDM superchannels scheme with different modulation techniques and subchannel spacing can handle the total traffic capacity. For shorter superchannels using higher order modulation formats, it is possible to get a narrow slot width [16]. It is seen that higher order modulation formats are more beneficial to small geographical optical networks. In elastic optical networks, by the occupancy of the less optical spectrum by introducing higher order modulation format it is possible to achieve error free transmission with reduced impairments noise.

III. ILP MODEL AND PROBLEM FORMULATION

In this section, we first describe the ILP mode [4] considered for our study followed by assumptions and proposed spectrum utilization factor to estimate network survivability.

A. ILP Model

The author in [4] explains the ILP formulation to provide optical solution for a network which is used to minimize the total number of the frequency slot in the networks. In our work it is used

to calculate the number of used frequency slot with respect to the available frequency slot. The following notation is used in the mathematical model.

Given:

s:Sourse node

d: Destination node

f, k=Frequency slot.

r: Route in the network.

traf[s][d]: Traffic matrix for the network.

E[i][j]: Adjacency matrix for the network.

$\delta_{ij,r}^{sd}$: It is a binary that is set in case link is ij is used in route r to meet demand (s, d), and zero otherwise

$Dist_r^{sd}$: Number of hops in route r for sd.

N= value of frequency slots in (i, j).

$X_{ij,k}$: Binary; 1 if frequency slot 'k' is used in link (i, j), else '0'.

C_{rf}^{sd} :Binary output; 1 if the frequency slot 'f' is the highest slot reserved to between request (s, d) on route 'r', else '0'.

Objective Function:

$$Min : \sum_{w}\sum_{r}\sum_{f} traf[s][d] \times Dist_r^{sd} \times C_{rf}^{sd} \qquad (1)$$

The objective of this formula is to minimize the total use of network frequency slots.

Constraints:

$$\sum_{r}\sum_{f} C_{rf}^{sd} = 1 \qquad (2)$$

$$C_{rf}^{sd} \le X_{ij,k}^{r}; \begin{cases} \forall s, d/s \neq d \ and \ r \in R \\ f = 1, ..., (N - traf[s][d]) \\ \forall i, j/E[i][j] = 1 \\ k = f, ..., (f + traf[s][d]) \end{cases} \qquad (3)$$

$$\sum_{sd}\sum_{r}\sum_{f} \delta_{ij,r}^{sd} \times C_{rf}^{sd} - X_{ij,k} \le 0; \begin{cases} \forall k/k \ge f \ and \\ k \le f + traf[s][d] \end{cases} \qquad (4)$$

$$\sum_{k} X_{ij,k} \le N; \forall (i, j) \in E \qquad (5)$$

Constraints (2–5) are responsible for selecting the highest valued frequency slot for any traffic request.

B. Spectrum Utilization model

Due to the increasing growth of traffic demand, pre-knowledge of spectrum utilization capacity helps the network service provider to predict the survivability of the existing network. The ILP formulation is used to calculate the allocated frequency slot in a network, for all the source-destination pair to minimize the objective function. The formulation is for measurement of spectrum utilization and accordingly comparisons with the increase traffic demand.

Spectrum Utilization

= (Total Number of frequency slot used in all the link)/(Total number of available frequency slot available in all the link)

$$\eta_{su} = U/Umax$$

Where:

Umax is calculated by multiplying the number of available frequency slot in each fiber and the total number of link in the network. The value of U is the optimized value of used frequency slot using ILP.

$Umax = PN_E$

Where:

P=Number of available frequency slot in each fiber link

N_E=Number of fiber link

As per the network condition, the spectrum utilization is the ratio of the used frequency slot and the total number of available frequency slots for all source–destination (s, d) pair. For a particular value of assigned frequency slot N, the ILP formula returned the maximum traffic handling capacity of the network. The ILP will stop working at a particular value of the traffic for a particular value of 'N'. This indicates the maximum utilization capacity of the network. With the increase of the traffic due to the growth of traffic demand with time, using our analysis, it is possible to estimate the spectrum utilization of the networks and predict to upgrade the frequency slots of the EON.

IV. RESULTS AND DISCUSSION

In our simulation, we consider a six node EON network as shown in the Fig.4, where the number indicates the distance in kilometers. Using the ILP in this network by scaling the traffic load the network spectrum usability capacity is measured. The linear program computes the used slot in the network for a traffic load at a given number of available frequency slots. With higher value of traffic scaling the number of used slot also increased. In this work we have taken a traffic matrix and compute the number of used frequency slot (Table.II) using ILP of the EON and it corresponding spectrum utilization (Table.III). Here all the links are bidirectional in the network, which decide the allowable frequency slot.

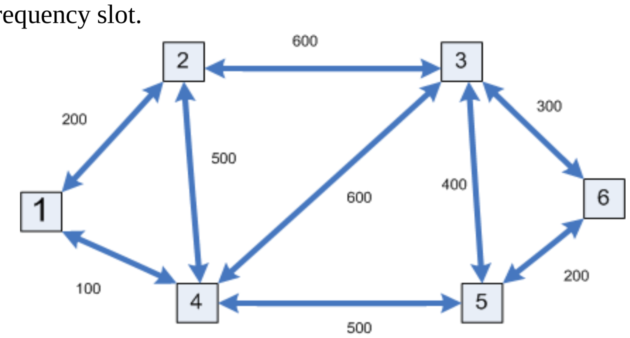

Fig.4. A six-node EON network with link distance in kilometers

The Fig.4 shows the physical topology with six nodes. Here we have calculated the all possible connection and routes for different value of N. It is used to find the occupied frequency slot for a given traffic to find spectrum utilization. Table -I shows the used traffic matrix, which is scaled-up and used in the simulation to find the maximum usable traffic by the network. Table-II, III shows the optimized values for different traffic demand with the available frequency slots in a EON.

Table- I: Traffic Matrix for six node network

Nodes	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6
Node 1	0	0	3	0	0	4
Node 2	0	0	0	0	9	0
Node 3	0	8	0	0	1	0

Node 4	0	8	0	0	0	0
Node	2	0	7	0	0	0

5						
Node 6	7	0	5	0	0	0

Table- II: Number of used frequency slot for a given traffic matrix.

Scaling Factor	Number of used frequency slot for a given traffic matrix. N=Maximum Number of available frequency slot in a link.						
	N=20	N=30	N=40	N=50	N=60	N=70	N=80
1	101	102	102	102	109	102	109
2	No Sol Exist	194	192	202	202	208	208
3	No Sol Exist	No Sol Exist	303	290	288	273	273
4	No Sol Exist	No Sol Exist	No Sol Exist	388	384	384	384
5	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	505	505	505
6	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	608	608
7	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	710
8	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist

Table- III: Spectrum Utilization for different value of frequency slots.

Scaling Factor	Spectrum Utilization=η_{su}=U/U_{max} for different number of frequency slot. N=Maximum Number of available frequency slot in a link.						
	N=20	N=30	N=40	N=50	N=60	N=70	N=80
1	0.25	0.17	0.12	0.102	0.09	0.0728	0.06
2	No Sol Exist	0.323	0.24	0.202	0.168	0.148	0.13
3	No Sol Exist	No Sol Exist	0.3787	0.29	0.24	0.195	0.1706
4	No Sol Exist	No Sol Exist	No Sol Exist	0.388	0.384	0.274	0.24
5	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	0.42	0.3607	0.3156
6	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	0.434	0.38
7	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	0.443
8	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist	No Sol Exist

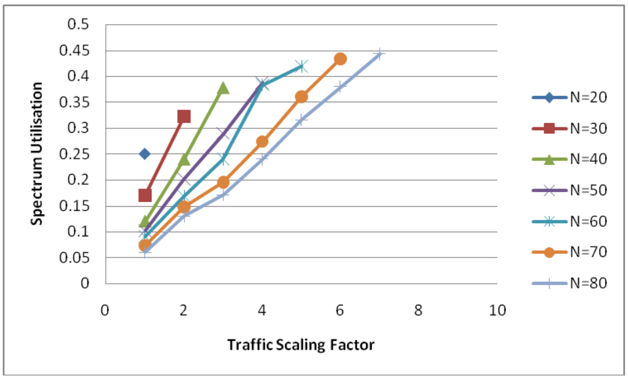

Fig. 5. Plot of Spectrum utilization verses Traffic scaling factor

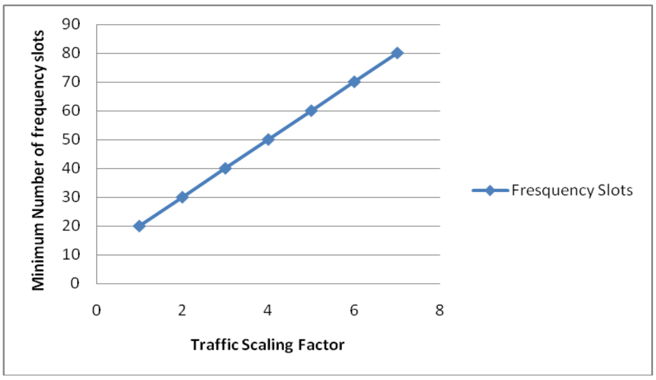

Fig. 6. Plot of minimum number of frequency slots verses Traffic scaling Factors

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Fig.5 shows the analysis of spectrum utilization verses traffic scaling factor for different value of available frequency slots in a network. It signifies the maximum number of scaling factor needed so that ILP will stop. Fig. 6 shows the minimum number of frequency slots required for different network traffic scaling factor. It is seen that with the increasing traffic, network need more frequency slot according to the ILP. This study results that our existing EON can handle the traffic up to a particular scale. Another useful observation can be made by determining the minimum number of frequency slots need to support a given traffic scaling factor and the value of the corresponding spectral utilization. These two plots indicate that the value of minimum number of frequency slots increases linearly with the value of scaling factor, spectrum utilization reaches saturation at higher value of traffic scaling factor.

V. CONCLUSION

In this paper we study the EON based on its architecture and calculate the spectrum utilization factor to estimate the capacity of the network. ILP is used to optimize the network to calculate the minimum number of the required frequency slots. Three parameters such as spectrum utilization factor, traffic scale-up factor and minimum number of frequency slot required to support a given traffic is used to estimate the capacity of the exiting EON. It is found that spectrum utilization factor attain a saturation at higher value of traffic scaling factor and the minimum number of required frequency slot increase linearly with the traffic scaling factor. This study also reviews the elastic optical networking from the viewpoint of Bandwidth variable transponders called elastic transponders and wavelength selective switches. In elastic optical networks due to distance adaptive modulation and rate adaptive superchannels, the spectrum efficiency of the optical network is increased. The adaptive spectrum in EONs makes it acceptable by researchers and different industrial activity. This technological growth allows a network to flexibly handle the wide variety of traffic demand efficiently.

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