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Network Blocking Probability Based Evaluation of Spectrum Fragmentation in Elastic Optical Networks

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Abstract- In Elastic Optical Networks (EONs), overcoming spectrum contiguity and continuity constraints is a challenging task while allocating spectrum slots (SS) to an incoming traffic demand. The frequent setup and release of SS over spectrum paths (SP) lead to unused isolated non- contiguous SSs. These isolated SS becomes unusable for future connections and causes significant fragmentation of spectral resources and degrades the network performance. This paper presents a spectrum assignment (SA) strategy that allocates SS based upon the relative difference between the required SS width and available SS width. The performance of proposed SA technique is evaluated in terms of Network Blocking Probability (NBP) by carrying out simulations under variable load conditions. The comparative analysis shows that the proposed strategy reduces spectrum fragmentation effectively as compared to existing SA strategies.

Keywords: EONs, Routing and Spectrum Assignment (RSA), SS, NBP, Orthogonal Frequency Division Multiplexing (OFDM), SP, National Science Foundation Network Topology (NSFNET)

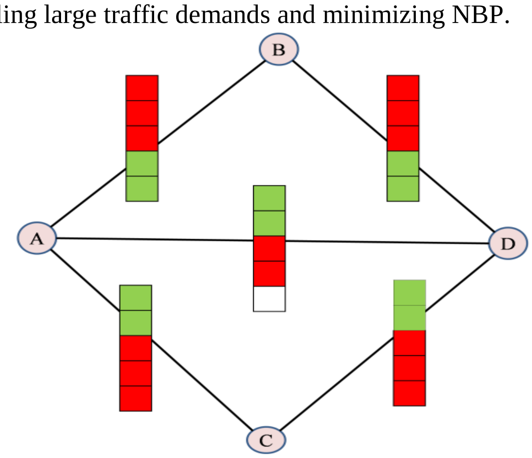
I. INTRODUCTION

The recent bandwidth hungry multimedia applications require huge bandwidth in order to provide seamless services. Optical Backbone networks based on Dense Wavelength Division Multiplexing technology uses ITU-T fixed grid spectrum allocations, fails to serve these exponential and heterogeneous bandwidth demands. EONs are OFDM based networks that provides flexibility in allocation of spectral resources, and can cater this ever increasing traffic demand efficiently [1][2].

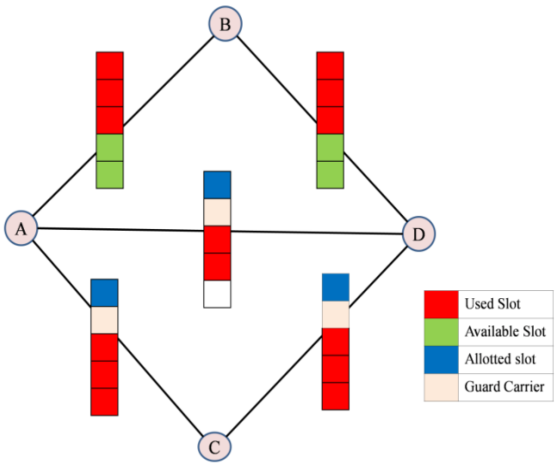
In EONs, while assigning spectral resources, each adjacent orthogonal subcarrier in OFDM must be consecutive for better spectrum efficiency. All these complexities and constraints in selecting a route along with an efficient SA strategy are termed as RSA. In Fixed routing approaches, routes for each source-destination pair are predetermined and routes are established using minimum hop and shortest path algorithms such as Dijkstra's algorithm. While in adaptive routing algorithms, a least loaded route is determined dynamically upon arrival of a connection request.

All these single path routing algorithms may not find contiguous SS when the network is fragmented leading to blocking of connection request. Multipath Routing (MR) provides advantage of using more than one SP by splitting a connection request into multiple smaller requests and assign SS on different routes to these requests. However assigning multiple paths may require use of guard carriers that may limit spectrum utilization.

Figure 1, shows the concept of MR with a five node network with five links. Each link having five SS and requires one SS as guard carrier while servicing connection request. From Figure 1(a), when a traffic request with two SS arrives at A to node C, the request is blocked as the required three SS (two SS for request and one for guard carrier) are not available on the link AC. However, using MR the same connection request can be splitted into two request of one SS each and can be transferred over the links AC and ADC with one guard carrier on each link as shown in Figure 1(b). Therefore MR based RSA schemes are much efficient in handling large traffic demands and minimizing NBP.



(a) Network state before RSA



(b) Network state after RSA

Figure 1: Illustration of RSA using Multipath Routing [3]

SA strategies consider the spectrum contiguity and continuity constraints for efficient spectrum utilization. In spectrum continuity constraint, all the SS over the assigned SPs for a connection request should have same SSs. Spectrum contiguity means if a connection request requires *N* number of SSs, then these *N* SSs must neighbor each other. The various elastic SA strategies have been discussed extensively in literature. In FF SA policy, a lower indexed SS from a list containing all the SSs available over the network is used to serve the connection request. In Random Fit (RF) policy, a SS is selected randomly from the list of available slots. The selected SS, after the completion of connection request are returned to available slots list. The Last Fit (LF) policy works opposite to that of FF policy and chooses a highest indexed slot from the list of available slots. FF policy provides lesser NBP as compared to other SA strategies. [4]

The organization of paper is as follow: Section 2 provides a brief description of spectrum fragmentation occurring in EONs and various fragmentation metrics. Section 3 contains the related work found in literature. Section 4 demonstrates the design and simulation setup using proposed slot based SA strategy. Section 5 contains results and discussion and section 6 concludes the paper.

II. SPECTRUM FRAGMENTATION

In EONs, while allocating spectrum paths to dynamic traffic demands, the RSA algorithms have to consider spectrum continuity and contiguity constraints. The frequent setup and release of SS over spectrum paths leads to unused, isolated non contiguous SSs. These isolated and unused SS becomes unusable for future connections and causes significant fragmentation of spectral resources. Fragmented spectrum has a degrading effect in network performance, as increased fragmentation leads to increased NBP and reduced spectrum usage efficiency.

Figure 2 shows an illustration of how a connection request for a traffic demand can be blocked because of unavailability of continuous and contiguous SS due to fragmentation. In Figure 2(a), a connection request with a demand of two contiguous and three continuous slots request a SP from source to destination over three links. Figure 2(b) shows that the spectrum consists of two contiguous SS for each link 1, 2 and 3. But these SS are not continuous hence connection request is blocked due to non availability of continuous /aligned SS. In Figure 2(c), each link has two group three continuous/aligned SS but these SS are not contiguous therefore the connection request is blocked. From figure 2, although two free SS are available in each link but due to fragmented spectrum, the connection request is blocked.

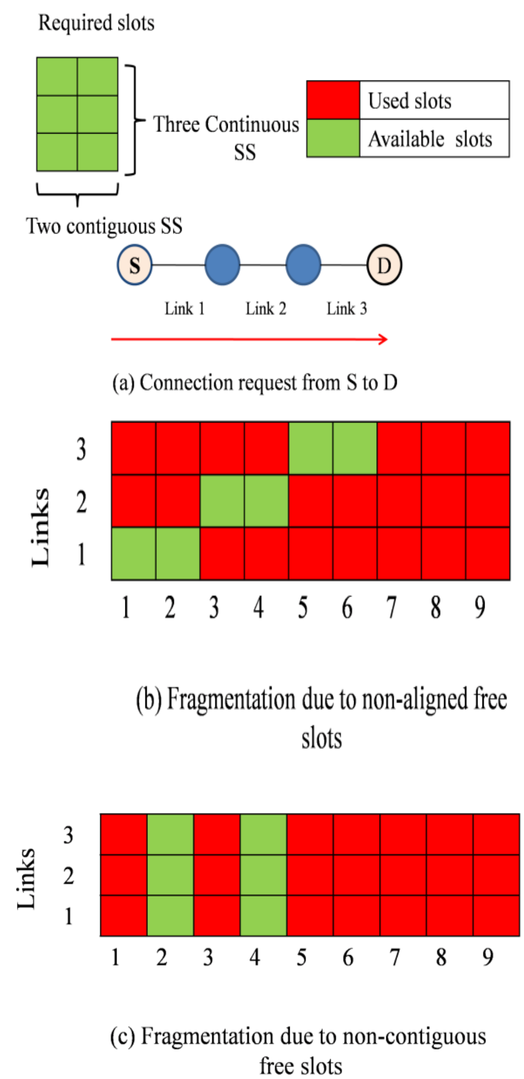
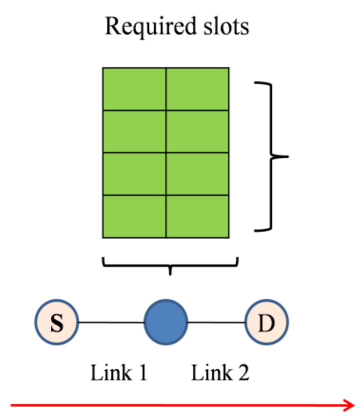
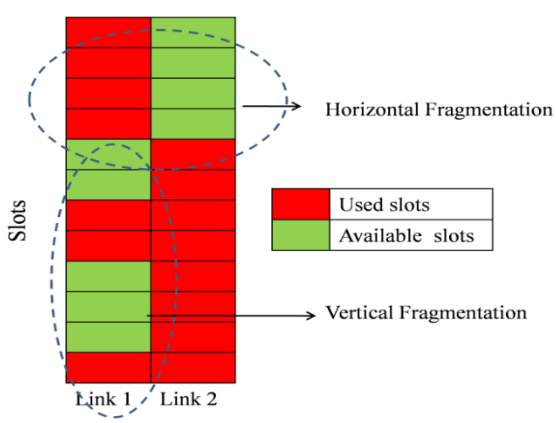


Figure 2: Spectrum Fragmentation due to non-continuous and non-contiguous spectrum Slots [5].

Figure 3(a) and 3(b) shows a different concept of horizontal and vertical fragmentation occurring due to spectrum contiguity and continuity constraints. Figure 3 (a), shows an incoming request with four contiguous and two continuous SS from source to destination through link 1 and 2. From figure 3(b), horizontal fragmentation occurs due to spectrum continuity constraint in which the same block of spectrum may not be available to serve traffic demands along the successive links of a SP although the SP may have sufficient SS for serving the incoming request.
The vertical fragmentation occurs due a situation in which the SS over a link are fragmented into non-contiguous blocks. These non-contiguous SS cannot be allocated to a large demand and the incoming request is thus blocked. Spectrum Fragmentation causes degrading effects that limits network performance. It increases NBP and thus reduces network utilization efficiency. As the unused SSs remain scattered and not enough contiguous SS may be available over the SPs that may lead to blocking of high-bandwidth connections and leads to starvation of higher bandwidth services.



(a) Connection request from S to D



(b) Horizontal and Vertical Fragmentation
Figure 3: Horizontal and vertical Spectrum Fragmentation

In order to judge the effectiveness of any RSA strategy and to monitor the exact level of fragmentation over a SP, a correct defragmentation metric must be used. Many fragmentation metrics have been reported in the literature. These metrics access the current state of fragmentation in the network and quantifies the level of fragmentation. The various fragmentation metrics are explained as follows.

External Fragmentation metric (F_{EF}): F_{EF} metric calculates the ratio of largest available contiguous free SS to the total number of available free slots.

$$F_{EF} = 1 - \frac{LC_{SS}}{AF_{SS}} \qquad (1)$$

Where LC_{SS} is the largest available contiguous free SS, AF_{SS} is total available free SS in the entire link.
EF provides a value that is correlated with the fragmentation level. EF metric only consider largest available contiguous free SS but not the other available smaller spectrum fragments.

Fragmentation Metric based on Shannon Entropy (F_{SE}): The information content in a message is measured using entropy. This concept of entropy can be used a metric to measure level of fragmentation. This metric is defined as

$$F_{SE} = \sum_f \frac{T_f}{T} \ln \frac{T}{T_f} \qquad (2)$$

Where f denotes a free spectrum fragment and T_f is number of SS in f. T , represent the total free SS in the link.
Like F_{EF} metric, F_{SE} also doesn't consider absolute loss and hence cannot conclude whether the spectrum is fully fragmented or not.

Access Blocking Probability Metric (F_{ABP}): F_{ABP} metric proposed in [6], is based upon transponder granularity. It can be used to quantify or estimate the level of fragmentation. The ABP can be mathematically expressed as:

$$F_{ABP} = 1 - \frac{\sum_{i=1}^{n}\sum_{k=1}^{m} DIV(f_i, G_k)}{\sum_{j=1}^{m} DIV(T, G_j)} \qquad (3)$$

Where T is the total number of available free SS, G is set of available granularity. G_k is the required number of SS type k granularity.
F_{ABP} can estimate relative fragmentation as it gives values between 0and 1, where 0 indicate free and contiguous spectrum and 1 indicates complete fragmentation. If all the spectrum fragments are smaller than the smallest granularity, then F_{ABP} returns a value of 1 indicating complete fragmentation.

III. RELATED WORK

In [6], the authors have presented a comprehensive description of various fragmentation metrics and state of art technology in spectrum defragmentation. Authors have also proposed Access Blocking Probability (ABP) as a performance metric in evaluation of spectrum fragmentation problems in both static and dynamic traffic environment. The authors evaluated the performance from the context of operator network considering transponder granularity and result shows improved performance as compared to FF strategy. In [7], the authors have analyzed the effect of bandwidth fragmentation on NBP and identified that the availability of spectrum blocks on lightpaths and the sizes of available spectrum blocks as a major constraint in resource utilization in EONs. From theoretical and numerical analysis, the authors concluded that relation among bandwidth fragmentation, bandwidth distribution, NBP and spectrum utilization must be considered for designing an efficient defragmentation strategy.

In [8] the authors have proposed a proactive bandwidth defragmentation based RSA algorithm that selectively reroutes existing connections with best effort traffic migration to minimize traffic disruptions. Simulative results show that proposed algorithm required rerouting of only 30% existing connections with less than 1% traffic disruption for efficient spectrum utilization and the further use of move-to-vacancy **(**MTV) approach reduced the traffic disruption upto 0.25%. A grouped elastic SA strategy for EONs based upon channel grouping is proposed in [9] .The proposed strategy reconfigures the push-pull spectrum reallocation strategy with in an acceptable waiting time for a service request. The simulative result shows that the proposed strategy reduces the bandwidth requirement per channel for a specified waiting time. The proposed strategy also specified a margin bandwidth among neighbor channels for seamless service delivery without requiring frequent reconfigurations.

In [10] the authors have presented entropy based quantitative metric for spectrum fragmentation based upon adaptive waveform analysis using orthonormal bases and provides efficient compressions of signals. The authors presented a RSA algorithm for EONs, based upon Shannon entropy as a performance metric [11]. The result shows that a considerable improvement of 10% in NBP was achieved using proposed algorithm under dynamic conditions as compared to existing RSA algorithms.

In [12], the authors have presented a Markov Chain (MC) based analytical model for performance evaluation of Flex grid WDM networks. The performance was evaluated based upon resource utilization rate, NBP and fragmentation rate as performance metrics. In [13] the authors presented a MC based analytical model for spectrum fragmentation in EONs. The proposed model efficiently quantifies the NBP in two distinct set of services: low data rate circuits with a channel of one spectrum slice and high data rate circuits using a superchannel mechanism over a single fiber. The authors in [14] present a novel SA strategy for efficient allocation of spectral resources in EONs. The authors presented the model as a stochastic process using MC .The performance of proposed strategy is compared with existing strategies based upon NBP and fragmentation ratio. The proposed strategy works optimally and provides minimum NBP and fragmentation ratio.

The authors in [15], proposed a subcarrier-slot partition scheme with first-last fit SA for EONs which increases the number of contiguous aligned available SS. The performance of proposed strategy was evaluated and compared with partitioned and non partitioned based FF and RF SA strategies .The proposed strategy was successful in creating more number of contiguous SS as compared to other strategies. Simulative result shows that the proposed strategy provides reduced NBP while accommodating 33.33% more traffic volume as compared to FF SA strategy [16]. The authors in [17] separated the two dimensional spectrum fragmentation into fragmentation and misalignment sub problem. The authors also proposed a joint RSA algorithm and evaluated its performance with respect to k shortest path algorithm. Simulative result shows that the proposed algorithms works efficiently and provides a significant reduction in NBP upto 4.43% from 96.62%.

In [18], the authors proposed two modified fragmentation aware RSA algorithms while considering distribution of traffic bandwidth and the carrying capability of SS. The authors proposed a low complexity fragmentation-aware load-balanced shortest path routing scheme (FL-SPR) and a modified fragmentation-aware load-balanced k-shortest-path routing scheme (FL-KSPR) .The performance of proposed algorithms was evaluated using network accommodation and computational complexity as performance metric. Results show that the proposed algorithms give an improvement of upto 39.09% in network accommodation and a reduced computational complexity upto 80% was achieved.

The authors in [19] proposed a mechanism to reduce fragmentation by assigning demand based constant spectrum blocks to incoming traffic request. Simulative results reaffirm that the constant slot assignment strategy out performs elastic spectrum assignment strategy and provides reduced NBP. In [20] the author proposes a RSA algorithm based on Minimized variable-grouping (MVG) mechanism. Performance evaluation shows that the proposed algorithm by minimizing the grouped spectrum resources can reduce the NBP upto 78% for lower network load and upto 6% for heavy load condition. The number of spectrum fragments reduced upto 87% compared with the typical ungrouped FF RSA algorithms**.**

In [21], the authors have proposed a novel dynamic RSA method to reduce spectrum fragmentation by providing immediate reservation or advanced reservation to the incoming traffic profile. The performance of the proposed scheme was evaluated using NBP as a performance metric. Simulative result shows that the proposed algorithm was successful in reducing NBP along with overall optimum utilization of resources. The authors in [22] have proposed two schemes for effective handling of spectrum fragmentation: a proactive and a reactive defragmentation scheme. These schemes utilize the hold time of incoming traffic request for efficient handling of network resources.

Simulative result shows that the proposed schemes were effective in reducing NBP and enhancing spectrum utilization.

In [23], the authors have analyzed the effect of fragmentation rate on different network models based upon proactive and reactive defragmentation schemes. The authors also proposed a novel combined Proactive Reactive-Delayed (Pro-Re-DL-DF) model that handles connection requests in scheduled manner. The authors further analyzed defragmentation as a service (DaaS) using proposed schemes and compared the results with FF and RF SA strategy. Simulative results show that the proposed scheme effectively reduces NBP. In [24], the authors proposed a hitless defragmentation algorithm for EONs using fast wavelength tracking in coherent receivers. Experimental demonstration shows that the proposed scheme was efficient in reducing the NBP upto a factor of 40 with improved BER performance.

The authors in [25] proposed auto defragmentation method that continuously ‘defrags’ the spectral fragments flexible grid optical networks without causing any service disruption. Simulative result shows that the proposed method was successful in reducing NBP upto 76%. The authors further concludes that proposed method along with advanced optical components can paved way for self optimizing EONs. In [26], the authors have presented Hitless Optical Path Shift (HOPS) based reactive and proactive defragmentation algorithms for EONs. The simulative results shows that using reactive defragmentation schemes upto 98% of spectrum bandwidth can be optimally utilized with reduced spectral fragmentation.

In [27], the authors have proposed a novel push-pull defragmentation technique for EONs utilizing coherent reception and tunable transmitter laser and tunable local oscillator at the receiver. The simulative result shows that the proposed technique was successful in reducing NBP considerably. The authors in [28] presented hitless bandwidth defragmentation algorithms for EONs using spectrum sweeping and hop tuning mechanisms. Simulative result shows that hop tuning technique achieved better performance and was successful in reducing NBP.

In [29], the authors evaluated spectrum defragmentation in EONs using a two-dimensional fragmentation evaluation method. Further the proposed an algorithm for a multi-path fragmentation-aware routing, modulation and spectrum assignment algorithm (RMSA) for advance reservation (AR) and immediate reservation (IR) requests. Simulative result shows that the proposed algorithm was efficient in reducing NBP and enhancing spectrum utilization efficiency.

The earlier work reported in literature have successfully suggested various techniques and algorithms for mitigation of defragmentation problems in isolation. In this paper we have extended our previous work on slot based SA algorithm that allocates SS based upon the relative difference between the slots required by incoming traffic demand and the SS present in candidate set. The proposed algorithm allocates SS that has minimum difference with that of required slot width. In this work, we have evaluated the performance of the proposed SA algorithm for effective defragmentation of spectral resources in terms of variation of NBP with network load using F_{ABP} as a fragmentation metric.

IV. SIMULATION SETUP

For simulations, several assumptions have been taken into consideration. Each fiber link has equal number of SSs and has same bandwidth. The incoming traffic demands follow a Poisson distribution with a hold-time of 150 msec. Each links has 80SS of 12.5GHz each that provides bandwidth of 1THz. The modulation formats considered are BPSK, QPSK and 8-QAM. Table II presents the various parameters used during simulations.

Table II: Parameters used in Simulation

PARAMETER	VALUE
Central Frequency	193.4THz
SS Bandwidth	12.5GHz
Bandwidth (Reference)	12.5GHz
Data Transmission Rates	50,100,400 Gbps
Noise Figure	3.162dB
Input OSNR	30dB
SS per link	80
Spectrum Select Switch loss	5dB

Let the Incoming traffic request t_{ri} can be expressed as $t_{ri} = f(s_{ti}, d_{ti}, b_{ti}, h_{ti})$ where s_{ti} is the source node, d_{ti} is destination node , b_{ti} is bandwidth required for incoming request and h_{ti} is the holding time for t_{ri}. The algorithm for proposed SA is given below.

Proposed SA Algorithm	
Step 1:	Input Incoming Traffic Demand ($t_{ri} = f(s_{ti}, d_{ti}, b_{ti, hti})$)
Step 2:	Compute Slot length (RS $_{tri}$) required for incoming traffic demand (t_{ri})
Step 3:	For each traffic demand, Select route *(loop#1)* Compare RS $_{tri}$ with SS from Candidate Set For RS $_{tri}$ less than or equal to SS *(loop #2)* Allocate Spectrum Slot (SS) End of *loop #2*
Step 4:	For hold time h_{ti} not equal to zero, return to *loop#1*
Step 5:	For each traffic demand (RS $_{tri}$), compute hold time(h_{ti}) *(loop #3)* For hold time (h_{ti}) not equal to zero, establish connection End of *loop#3* End of *loop#1*
Step 6:	For hold time h_{ti} equal to zero ,terminate request

When a traffic request $t_{ri} = f(s_{ti}, d_{ti}, b_{ti, hti})$ arrives, the required SS width (RS_{tri}) is calculated. Shortest path routing algorithm is used for route selection. If the route is found and the hold time (h_{ti}) is not zero then the connection request is accepted. The proposed SA assigns SS that have minimum difference or are equal to length t_{ri} . If a route is not found and the hold time expires then the request is terminated. We have carried out simulations using C++ IDE simulator using F_{ABP} (equation 3) as metric for quantifying fragmentation level and NBP as performance metric over 14 nodes 21link NSFNET Topology as shown in Figure 5[30].

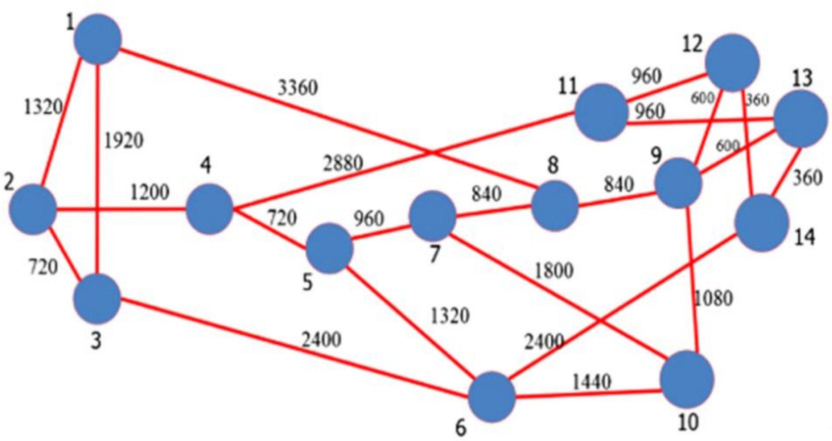


Figure 5: NSFNET topology with 14 nodes 21link along with distance (in Km) between nodes [30]

V. RESULT and DISCUSSION

We have evaluated the performance of proposed SA strategy and a comparison is done with existing FF and RF SA strategy. The performance is evaluated using NBP as performance metric and F_{ABP} is taken as fragmentation metric with a granularity of 4 SS. Figure 6 shows the values of NBP with variation in network load from 100 Erlangs to 600 Erlangs.

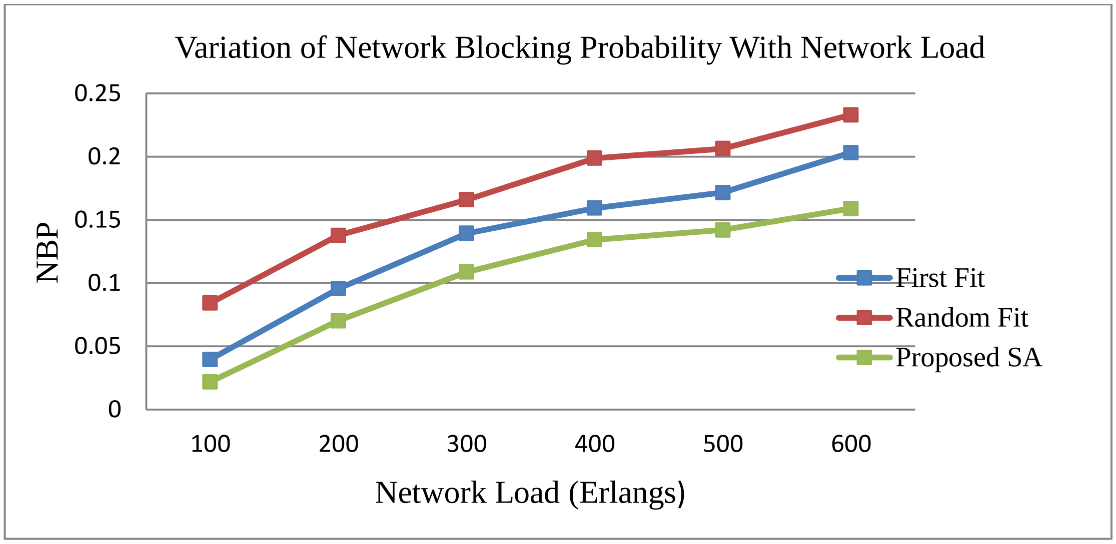


Figure6: Variation of Network Blocking Probability with Network Load

Figure 6 shows the values of NBP with variation in network load from 100 Erlangs to 600 Erlangs. As network load increases, NBP increases for all SA strategies. The proposed SA provides minimum NBP as compared to FF and RF strategy and hence works efficiently in reducing fragmentation of spectral resources. The above graphical results are tabulated in the Table III given below.

Table III: Variation of Network Blocking Probability with Network Load

Network Load (Erlangs)	First Fit	Random Fit	Proposed SA
100	0.0396	0.0842	0.0219
200	0.0956	0.1377	0.07013
300	0.1393	0.1659	0.1088
400	0.15936	0.1988	0.1343
500	0.1716	0.2064	0.1420
600	0.2032	0.2331	0.1589

The performance of proposed SA strategy is further evaluated with different spectrum granularities. The performance is evaluated in terms of NBP with three values of spectrum granularity of 4, 8 and 16 SS. Figure 7 shows the variation of NBP with increase in network load at different values of spectrum granularity.

With increase in spectrum granularity, the minimum free and contiguous SS required to assign SP to an incoming request increases. The NBP also increases due to increased spectrum fragmentation. The above graphical results are tabulated in the Table IV given below.

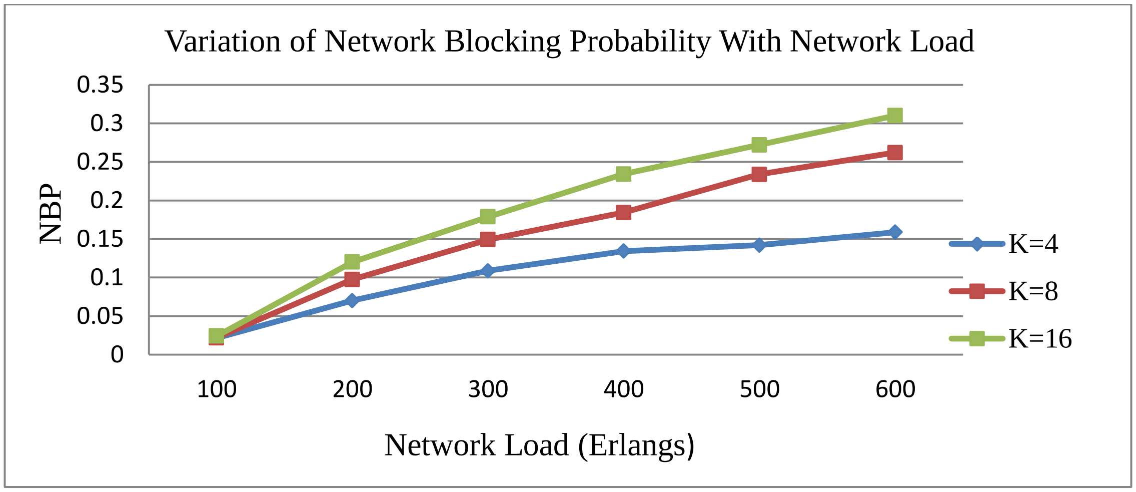


Figure 7: Variation of Network Blocking Probability with Network Load at different granularity.

Table IV: Variation of Network Blocking Probability with Network Load at different granularity.

Network Load (Erlangs)	Spectrum Granularity (G_K)		
	K=4	K=8	K=16
100	0.0219	0.0220	0.0242
200	0.07013	0.0977	0.1203
300	0.1088	0.1493	0.1788
400	0.1343	0.1844	0.2343
500	0.1420	0.2338	0.2720
600	0.1589	0.2621	0.3100

From Figure 7 and Table IV, it can be concluded that by selecting proper spectrum granularities using F_{ABP} metric, spectral resources can be managed efficiently. We further analyzed the proposed SA strategy using multipath routing algorithm and the performance is compared with fixed RSA strategy as shown in Figure 8.

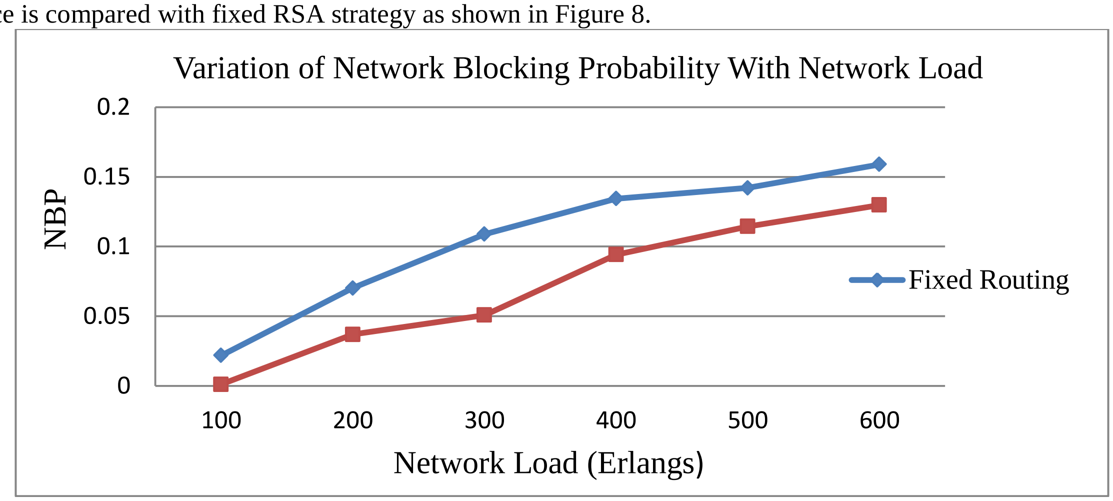


Figure8: Comparison of proposed SA strategy over fixed and multipath routing schemes

As multipath routing algorithm, divides a traffic demand requiring large number of SS into multiple smaller demands requiring fewer SSs. The multiple traffic demands are then routed over separate paths and thus help in reducing spectrum fragmentation. Thus the proposed SA strategy with multipath routing algorithm works efficiently and provides lesser NBP as compared with fixed RSA strategy. The above graphical results are tabulated in the Table IV given below.

Table V: Comparison of proposed SA strategy over fixed and multipath routing schemes

Network Load (Erlangs)	Fixed Routing	Multipath Routing
100	0.0219	0.0011
200	0.07013	0.0369
300	0.1088	0.0508
400	0.1343	0.0942
500	0.1420	0.1144
600	0.1589	0.1297

From Figure 8 and Table V, it is evident that the proposed SA strategy along with multipath routing performs efficiently and helps in reducing NBP. The proposed SA strategy provides an improvement of 46 percent in reducing NBP over FF and RF SA strategy. The use of multipath routing reduces NBP significantly with minimum traffic interruption and a further improvement of upto 22 percent is obtained at 600Erlangs traffic load.

VI. CONCLUSION

This paper presents NBP based evaluation of spectrum defragmentation in EONs using a proposed slot based SA strategy. The performance of proposed SA is evaluated and compared with FF and RF SA strategy on the basis of variation of NBP with increase in network load using standard NSFNET topology and ABP as a fragmentation metric. Simulative result shows that the proposed SA strategy performs efficiently and provides 46% less NBP as compared to FF and RF SA strategies at a spectrum granularity of 4 slots. Further using multipath routing, the performance of proposed SA strategy is compared with fixed routing and an improvement of 22% is obtained at a network load of 600Erlangs. Thus the use of proposed SA strategy reduces spectrum fragmentation considerably and enhances the efficiency of EONs in handling network resources in an effective and optimal manner.

REFERENCES

[1] Deepak Sharma, Suresh Kumar, “An Overview of Elastic Optical Networks and its Enabling Technologies”. International Journal of Engineering and Technology (IJET) Vol. 9 No 3 Jun-Jul 2017, pp (1643-1649) ISSN 0975-4024 DOI: 10.21817/ijet/2017/v9i3/170903022.

[2] Deepak Sharma, Suresh Kumar, “Design and Evaluation of OFDM Based Optical Communication Network” Journal of Engineering and Applied Sciences Vol. 12 S. Issue 2 ,(2017)pp:6227-6233 DOI:10.3923/jeasci.2017.6227.6233.

[3] Shakya, Sunny, "Management of Spectral Resources in Elastic Optical Networks." Dissertation, Georgia State University, 2015.

[4] Deepak Sharma, Suresh Kumar, “Evaluation of Network Blocking Probability and Network Utilization Efficiency on Proposed Elastic Optical Network using RSA Algorithms.” Journal of Optical Communications, 0(0),(aop) (2018). doi:10.1515/joc-2017-0204

[5] B. C. Chatterjee, S. Ba and E. Oki, "Fragmentation Problems and Management Approaches in Elastic Optical Networks: A Survey," in IEEE Communications Surveys & Tutorials, vol. 20 pp. 183-210, 2018. doi: 10.1109/COM2017.276102

[6] D. Amar, E. Le Rouzic, N. Brochier, J.-L. Auge, C. Lepers, and N. Perrot, “Spectrum fragmentation issue in flexible optical networks: analysis and good practices,” Photon. Netw. Commun., vol. 29, no. 3, pp. 230–243,

[7] W. Shi, Z. Zhu, M. Zhang, and N. Ansari, “On the effect of bandwidth fragmentation on blocking probability in elastic optical networks,” IEEE Trans. on Commun., vol.61, no.7, pp.2970–2978,(2013). doi:10.1109/TCOMM. 053013.120853.

[8] M. Zhang, W. Shi, L. Gong, W. Lu, and Z. Zhu, “Bandwidth defragmentation in dynamic elastic optical networks with minimum traffic disruptions,” in IEEE International Conference on Communications (ICC), Budapest, 2013, pp. 3894-3898.doi: 10.1109/ICC.2013.6655165.

[9] M. Chino, T. Miyazaki, E. Oki, S. Okamoto, and N. Yamanaka, “Adaptive elastic spectrum allocation based on traffic fluctuation estimate in flexible OFDM-based optical networks.” in IEEE 17th International Conference on High Performance Switching and Routing (HPSR), Yokohama, 2016, pp. 81-86. doi: 10.1109/HPSR.2016.7525643

[10] R. R. Coifman and M. V. Wickerhauser, “Entropy-based algorithms for best basis selection,” IEEE Trans. on Inform. Theory, vol. 38, no. 2, pp. 713–718, (1992) doi: 10.1109/18.119732.

[11] P. Wright, M. C. Parker, and A. Lord, “Simulation results of Shannon entropy based flexgrid routing and spectrum assignment on a real network topology,” 39th European Conference and Exhibition on Optical Communication (ECOC 2013), London, 2013, pp. 1-3. doi: 10.1049/cp.2013.1428 .

[12] Y. Yu, J. Zhang, Y. Zhao, X. Cao, X. Lin, and W. Gu, “The first single-link exact model for performance analysis of flexible grid WDM networks,” Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference (OFC/NFOEC), Anaheim, CA, 2013, pp. 1-3.

[13] J. Kim, S. Yan, A. Fumagalli, E. Oki, and N. Yamanaka, “An analytical model of spectrum in a two-service elastic optical link,” IEEE Global Communications Conference (GLOBECOM), San Diego, CA, 2015, pp. 1-6. doi: 10.1109/GLOCOM..7417243

[14] A. Rosa, C. Cavdar, S. Carvalho, J. Costa, and L. Wosinska, “Spectrum allocation policy modeling for elastic optical networks,” High Capacity Optical Networks and Emerging/Enabling Technologies, Istanbul, 2012, pp. 242-246. doi: 10.1109/HONET.2012.6421472

[15] B.C. Chatterjee and E. Oki, “Performance evaluation of spectrum allocation policies for elastic optical networks,” in 17th

International Conference on Transparent Optical Networks (ICTON), 2015, pp. 1-4. doi: 10.1109/ICTO/.7193485

[16] W. Fadini, B.C. Chatterjee, and E. Oki, “A subcarrier-slot partition scheme with first-last fit spectrum allocation for elastic optical networks,” Computer Networks, Volume 91, 2015, Pages 700-711, https://doi.org/10.1016/ 2015.08.048.

[17] Y. Yin, H. Zhang, M. Zhang, M. Xia, Z. Zhu, S. Dahlfort, and S. Yoo, “Spectral and spatial 2D fragmentation-aware routing and spectrum assignment algorithms in elastic optical networks [invited],” IEEE/OSA Journal of Optical Communications and Networking, vol. 5, no. 10, pp. A100-A106, Oct. 2013. doi: 10.1364/JOCN.5.00A100

[18] X. Chen, A. Jukan, and A. Gumaste, “Multipath de-fragmentation: achieving better spectral efficiency in elastic optical path networks,” in Proceedings IEEE INFOCOM, Turin, 2013, pp. 390-394. doi: 10.1109/INFCOM.2013.6566801

[19] J. Comellas, X. Calzada, and G. Junyent, “Efficient spectrum assignment in elastic optical networks,” in 18th International Conference on Transparent Optical Networks (ICTON), Trento, 2016, pp. 1-4. doi: 10.1109/ICTON.2016.7550506

[20] Y. Qiu, “An efficient spectrum assignment algorithm based on variable (2017), Pages 39-46, ISSN 1573-4277, https://doi.org/10.1016/j.osn.2016.11.005.

[21] S. Sugihara, Y. Hirota, S. Fujii, H. Tode, and T. Watanabe, “Dynamic resource allocation for immediate and advance reservation in spacedivision-multiplexing-based elastic optical networks,” IEEE/OSA Journal of Optical Communications and Networking, vol. 9, no. 3, pp. 183-197, March 2017. doi: 10.1364/JOCN.9.000183

[22] S. K. Singh and A. Jukan, “Efficient spectrum defragmentation with holding-time awareness in elastic optical networks,” IEEE/OSA Journal of Optical Communications and Networking, vol. 9, no. 3, pp. B78-B89, March 2017. doi: 10.1364/JOCN.9.000B78

[23] S. K. Singh, W. Bziuk, and A. Jukan, “Analytical performance modeling of spectrum defragmentation in elastic optical link networks,” Opt. Switching Netw., vol. 24, pp. 25–38, 2017 ISSN 1573-4277, https://doi.org/10.1016/j.osn.2016.11.001.

[24] R. Proietti, C. Qin, B. Guan, Y. Yin, R. P. Scott, R. Yu, and S. Yoo, “Rapid and complete hitless defragmentation method using a coherent RX lo with fast wavelength tracking in elastic optical networks,” Opt. Exp., vol. 20, no. 24, pp. 26 958–26 968, 2012. https://doi.org/10.1364/OE.20.026958

[25] X. Wang, I. Kim, Q. Zhang, P. Palacharla, and M. Sekiya, “A hitless defragmentation method for self-optimizing flexible grid optical networks,” in 38th European Conference and Exhibition on Optical Communications, Amsterdam, 2012, pp. 1-3. doi: 10.1364/ECEOC.2012.P5.04

[26] R. Wang and B. Mukherjee, “Provisioning in elastic optical networks with non-disruptive defragmentation,” Journal of Lightwave Technology, vol. 31, no. 15, pp. 2491-2500, Aug.1, 2013. doi: 10.1109/JLT.2013.2268535

[27] F. Cugini, M. Secondini, N. Sambo, G. Bottari, G. Bruno, P. Iovanna, and P. Castoldi, “Push-pull technique for defragmentation in flexible optical networks,” in Proc National Fiber Optic Engineers Conference, OSA Technical Digest (Optical Society of America, 2012), paper JTh2A.40. https://doi.org/10.1364/NFOEC.2012.JTh2A.40

[28] M. Zhang, Y. Yin, R. Proietti, Z. Zhu, and S. J. B. Yoo, "Spectrum Defragmentation Algorithms for Elastic Optical Networks using Hitless Spectrum Retuning Techniques," in Optical Fiber Communication Conference/National Fiber Optic Engineers Conference 2013, OSA Technical Digest (online) (Optical Society of America, 2013), paper OW3A.4. https://doi.org/10.1364/OFC.2013.OW3A.4

[29] R. Zhu, Y. Zhao, H. Yang, X. Yu, J. Zhang, A. Yousefpour, N. Wang, and J. P. Jue, “Dynamic time and spectrum fragmentation-aware service provisioning in elastic optical networks with multi-path routing,” Opt. Fiber Technol., vol. 32, pp. 13–22, 2016. ISSN 1068-5200 https://doi.org/10.1016/j.yofte.2016.08.009

[30] O.Pedrola, A. Castro, L. Velasco, M. Ruiz, J. P. Fernández-Palacios, and D. Careglio. "CAPEX Study for a Multilayer IP/MPLSOver-Flexgrid Optical Network", Journal of Optical Communications and Networking, 2012. Vol 4, Issue: 8, Aug. 2012 pp. 639 - 650 DOI: 10.1364/JOCN.4.000639 .

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