Review of Spectrum Fragmentation Minimization Techniques in Elastic Optical Networks

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Abstract-In Elastic Optical Networks(EONs), Spectrums are allocated contiguously, and allocating them dynamically can result in bandwidth fragmentation. Fragmentation can result in a call blocking in a network and result in difficulty in utilization of the split up spectrum slots from the rest of the spectrum, so it is necessary that we try to minimize fragmentation as much as possible. There are non-defragmentation techniques where spectrums are allocated in such a way that fragmentation is minimized and defragmentation techniques where the fragmented slots are utilized by compaction for example. Therefore, in this paper we will do a review of various Spectrum Fragment minimization techniques in Elastic Optical Networks.

Keywords- Elastic Optical Networks; Fragmentation;

1. INTRODUCTION

An Optical Network is basically a communication network used to exchange information by the means of an optical fiber cable between one end to another. An optical fiber has huge bandwidth capacity but the accessing rate of the user is limited to a few gigabits per second. So in order to utilize the best of the bandwidth of the fibers the concept of *Wavelength Division Multiplexing (WDM)* was introduced. WDM is a technique that works by multiplexing wavelengths of varying frequencies onto a single fiber channel. In WDM various virtual fibers are created and each virtual fiber is capable of carrying a different signal. WDM-based optical network divides the bandwidth of a single fiber into different wavelength channels. The space between adjoining channels as specified by the International Telecommunication Union (ITU)-T is either 50 GHz or 100 GHz, which is relatively large [1].

The concept of *Elastic Optical Networks (EONs)* was introduced to overcome the issues with the Wavelength Division Multiplexing (WDM)-based optical networks by providing a transfer speed of more than 100 gigabits per second, and by spectrum-efficient transfer of data obtained by the introduction of flexible granular grooming in the optical frequency domain. EON can allocate spectrum to light-paths as per the bandwidth requirement. The spectrum is divided into slots and different number of slots are allocated to optical connections. A result of this is greater network utilization efficiency in comparison to WDM-based optical network. EON also overcomes a problem that can occur in WDM-based optical network, that is, if only low bandwidth is being carried by the channels, and the large unused frequency gap doesn't allow transmission of traffic then a huge part of the spectrum will go to waste. In order to overcome the shortcomings of traditional optical networks, Jinno et al. [2, 3, 4, 5] introduced a spectrum efficient EON which is based on *Orthogonal Frequency Division Multiplexing (OFDM)* technology [6,7]. Where OFDM is a special class of multi-carrier modulation (MCM) scheme that can transmit a high speed data stream by splitting it into numerous orthogonal channels, which are referred as sub-carriers. Each sub-carrier carries a relatively low data rate [8]. In comparison to WDM-based optical networks, where there's spacing between the split up channels, EONs with the help of OFDM technology help the spectrum of the sub-carriers to overlap due to its orthogonality, which results in increase in the transmission spectral efficiency. OFDM [9,10] divides the data stream into multiple sub-streams which are parallelly sent on multiple sub-carriers. Every single sub-carrier can then be modulated on the basis of bit rate requirement and transmission reach [11, 12].

Routing and Spectrum Allocation (RSA) is considered one of the key functionalities in EONs because of its characteristics of information transparency and spectrum reuse. RSA is useful in (i) finding the proper route or path between a source and a destination pair, and (ii) allocating appropriate spectrum slots to the requested light-paths. The RSA problem has two basic constraints, namely continuity and contiguity. The continuity constraints require a light-path to use the same spectrum slot index on each link. The contiguity constraints require a light-path to be allocated to contiguous spectrum slots on a link. The RSA problem is an NP-hard problem [13, 14] but it can be simplified by dividing it into two separate sub-problems, which are : (i) routing sub-problem, and (ii) spectrum allocation sub-problem. We will discuss both the sub-problems in the paragraphs given below.

The routing sub-problem in EON can be solved by approaches which fall mainly into two groups, which are - (i) routing without elastic characteristics, and (ii) routing with elastic characteristics. The routing without elastic characteristics focuses on the following routing policies - (a) fixed routing, (b) fixed alternative, (c) least congested routing, and (d) adaptive routing.
With the goal of fitting the bandwidth requirements more precisely, the light-paths in the network may dynamically change the spectrum allocated to them, which is known as elastic spectrum allocation [15, 16]. Spectrum allocation can either be performed after finding a route for a light-path or it can be performed parallelly when we are selecting the route for the light-path. The spectrum range allocation for connection groups is done using the following policies –

(i) fixed spectrum allocation, (ii) semi-elastic spectrum allocation, and (iii) elastic spectrum allocation, based on the changes allowed to the resources that are allocated to light-paths in terms of spectrum width and *central frequency (CF).*

Fixed spectrum allocation **-** In this policy [15, 16] both assigned spectrum width as well as the central frequency remain fixed/static forever. This policy lacks elasticity.
Semi-elastic spectrum allocation **-** In this policy [15, 16] the central frequency remains static but the allocated spectrum width can vary in each time interval. It provides more flexibility as compared to static spectrum allocation.
Elastic spectrum allocation **-** In this policy both the allocated spectrum width as well as the central frequency can be changed in each time interval.

The allocation of spectrum slots for individual connection requests are performed using the any one of the following allocation policies [17]:
(i) First Fit **-** In first fit spectrum allocation [18,21], the slots are indexed and a list of indices of all available and used slots is maintained and the goal here is to choose the slot from the list of available slots which has the lowest index and allocate it to the light-path.
(ii) Random Fit - Here [18,19] a list is maintained consisting of all available slots and slot is randomly selected and allocated to the light-path request.
(iii) Last Fit **-** This policy [19, 20] tries to select the available slot with the highest possible index and allocate it to the light-path request.
(iv) First-last fit **-** In this policy [21], all the spectrum slots of every link is divided into a number of partitions. The lowest possible index is chosen for the odd number partition and the highest possible index is chosen for the even number partition.
(v) Least used **-** This allocates [19,22] the spectrum that has been used by the fewest fiber links in the network from the list of available spectrum slots to the light-path request.
(vi) Most used **-** This allocates [19,22] the spectrum that has been used by the most fiber links in the network from the list of available spectrum slots to the light-path request.

EONs allocate the spectrum on contiguous sub-carrier slots, and as the size of the sub-carrier slots is elastic, it can be narrower than a few Ghz. Thus, dynamic setup and tear down of connections can result in *bandwidth fragmentation* [13, 23] problem. When available slots get isolated from one another due to becoming non-contiguous in the spectrum or by misalignment along the path is bandwidth fragmentation. Due to this, it becomes difficult to utilize them for future light-path connection requests. In case the connection request's bandwidth request is not fulfilled by the available slots due to fragmentation, the connection request is said to be blocked/rejected. This is known as call blocking, and in this scenario a network operator has to reconfigure the optical paths and spectrum slots manually, which is known as defragmentation. In this paper we will review various ways to minimize fragmentation before the routes are assigned to light-path requests (non-defragmentation) and ways to minimize fragmentation that occurs after the spectrum have been assigned to the connections requests (Defragmentation).

2. LITERATURE REVIEW

2.1 Minimization of fragmentation in Elastic Optical Network

In Elastic Optical Network (EON), Fragmentation minimization can be done into two different ways. These are (a) Non-defragmentation Approach (b) Defragmentation. Note that non-defragmentation and defragmentation approaches are not mutually exclusive. One can make some schemes considering both non- defragmentation and defragmentation approaches.

2.1.1 Non-Defragmentation Approach

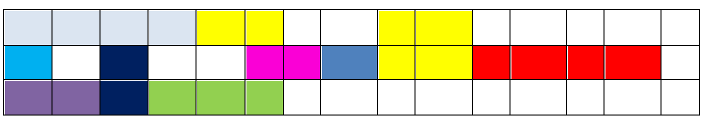
Main purpose the non-defragmentation approach is to avoid fragmentation before the allocation of a lightpaths, and in-case of defragmentation approaches, to minimize fragmentation there are several rules. In which after allocation of a lightpath we try to minimize it. In the non-defragmentation approach, the spectrum is considered in advance to avoid the fragmentation effect. The non-defragmentation approaches are attractive as they offer lower capital expenditure (CAPEX) and operational expenditure (OPEX) [1]. However, in this approach if traffic volume goes on high then performance for this approach will goes on decreases. In the non-defragmentation approaches, the following strategies are used to suppress the spectrum fragmentation.
In Non-Defragmentation approach there are following techniques for minimizing spectrum fragmentations. These are (a) Partitioning (b) Multi-path routing and (c) Multi-Graph

2.1.1.1 Partitioning Approaches

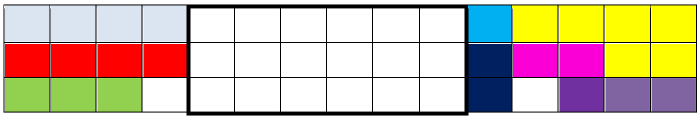
There are two ways of partitioning, These are (a) Pseudo Partitioning and (b) Dedicated Partitioning, In both the techniques have their own advantages and disadvantages also.

2.1.1.1.1Pseudo Partitioning

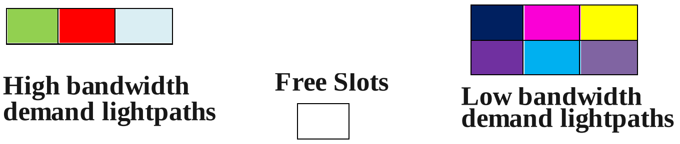
This approach [17] avoids the direct accommodation of mixed types of lightpaths. This partitioning is used to reallocate unsuccessful lightpath requests. This partitioning divide them into two groups and reallocating them to both ends of the spectrum slots. Suppose, a lightpath request has come and demands the bandwidth in the tables range is allocated resources from the lower end of spectrum. On the other hand, smaller requests are allocated resources from the higher end of the spectrum. We may create lightpath groups based on disjoint and non-disjoint [20] routes of lightpath requests. We can create light path groups using an integer linear programming (ILP) approach and heuristic approach. For large network ILP is not optimal so we can use Heuristic approach. There are different algorithm to solve this problem.



(a) without Pseudo partitioning



(b) Pseudo partitioning



In heuristic, it converts the problem into a graph, and creating the disjoint lightpath group in order to maximize the traffic demand. Here we use Path graph transformation algorithm multiple paths for all the source-destination pairs are determined in advance

Path graph transformation Algorithm: -

> *Input: All paths for all source-destination pairs*
> *Output: Path graph*
>
> **Step 1:** Initialize the set of vertices $V = \{\text{null}\}$ and the set of edges $E = \{\text{null}\}$.
> **Step 2:** Vertex generation.
> **2.1:** Generate vertex v that corresponds to each path, where $v = 1, 2, \cdots, |V|$ for $|V|$ paths, and the n add v to V.
> **2.2:** Generate vertex value w, which corresponds to each traffic demand of the path associated with vertex v.
> **Step 3:** Edge establishment.
> **3.1:** Establish edge (v, u) between $v \in V$ and $u \in V$ if the two paths corresponding to vertices v and u are multiple paths of the same source-destination pairs, add (v, u) to E.
> **3.2:** Establish edge (v, u) between $v \in V$ and $u \in V$ if the two paths corresponding to vertices v and u share at least one link, add (v, u) to E.

After transforming all the paths into the path graph, we maximize the total traffic demands in the disjoint connection group. We introduce a *largest value first algorithm* to select the relevant member of the disjoint connection group of a lightpaths. The largest value first algorithm is presented below. This algorithm assigns the member of the disjoint connection group in descending order of vertex value [1], where each vertex value represents a traffic demand for a lightpaths. In the initial stages, all the vertices are set to be unmarked vertices or in Boolean marked to be false. This algorithm selects an unmarked vertex with the largest value, and marks this vertex or true. If no adjacent vertex with the selected vertex belongs to the disjoint connection group, the

Largest Value First Algorithm: -

> *Input: Path graph*
> *Output: Disjoint lightpath group with maximum traffic demand*
>
> **Step 1:** Select the unmarked vertex with the largest value, mark the selected vertex.
> **Step 2:** If no adjacent vertex with the selected vertex belongs to the disjoint connection group, goto step3. Otherwise, goto step4.
> **Step 3**: Put the selected vertex into the disjoint connection group.
> **Step 4:** If all the vertices are marked, the algorithm stops. Otherwise, goto step1.

selected one is put into the disjoint connection group. This algorithm repeats the same procedure until all the vertices are marked or marked as true.

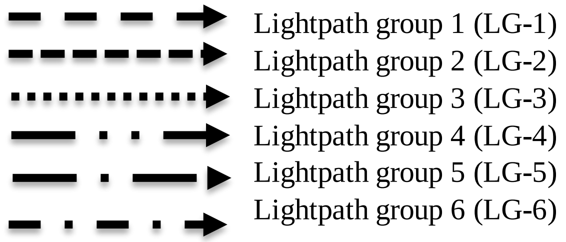
Once the disjoint and non-disjoint lightpath groups are determined, the first- last-exact fit spectrum allocation policy is adopted for spectrum allocation. The first-last-exact allocation policy is a combination of two allocation policies, namely, (i) first-exact fit and (ii) last-exact fit. The first-exact fit allocation policy is performed on lightpaths whose paths belong to the disjoint lightpath group. Last-exact fit allocation policy is performed on lightpaths whose paths belong to the non-disjoint lightpath group.

2.1.1.1.2 Dedicated Partitioning

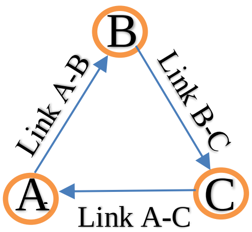
In dedicated partitioning approaches, we divide entire spectrum into a number of partitions based on certain criteria, criteria can be anything, and each partition is allocated to a different lightpath group. Dedicated partitioning is the strict version of the pseudo partitioning. In dedicated partitioning approaches, it is assumed that each light group must have the route and slot demand [20]. Using graph coloring Algorithm or method we can get required number of partitions [25]. if two lightpath groups share at least one common link with each other, then they are connected via an edge. A lightpath group is formed by a set of lightpaths whose routes are exactly the same. The graph coloring problem assigns a color to each vertex with one condition constraint that the same color is not assigned to adjacent vertices; our objective is to minimize the number of colors. Number of colors will make no of partitions. In dedicated partitioning approaches number of partitions must be greater than two. The lightpath groups and number of partitions are created in advance before allocating; when a lightpath request arrives, the network checks which category the lightpath request belongs to and assigns it to the appropriate partition. Through careful partitioning, spectrum under-utilization which is caused by un- fairness can also be eliminated. The main disadvantage of partitioning techniques is that they fail to offer statistical multiplexing gain. Due to the lack of statistical multiplexing gain, blocking probability can increase in the network if the number of partitions is high.

Example: -

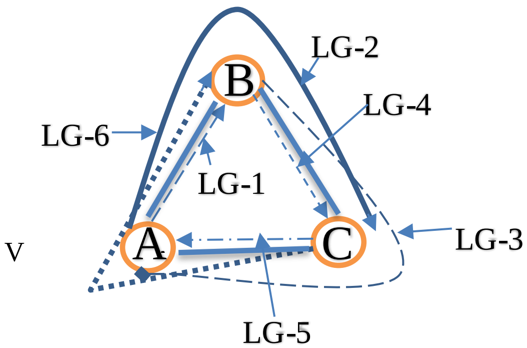
Below diagram shows all light paths group, suppose there are 6 light paths groups



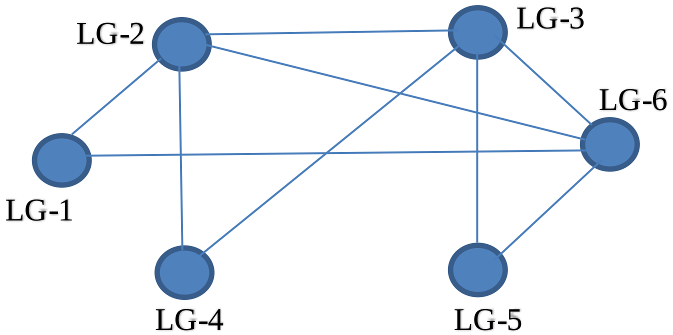
We are considering a three-node network here.



We assume that all lightpath requests are categorized into six lightpath groups; the routes of the lightpath groups are given in advance as shown

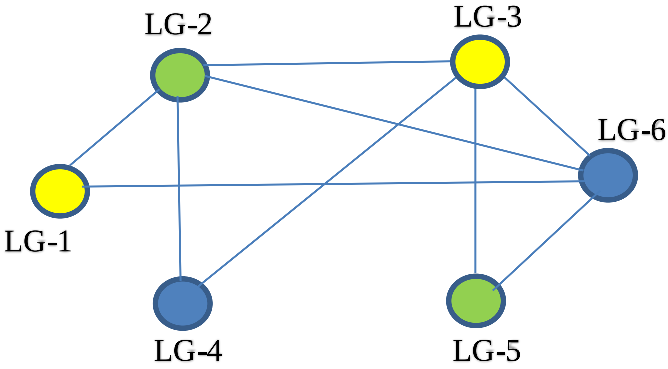


Using lightpaths group we can form auxiliary graph as shown below,



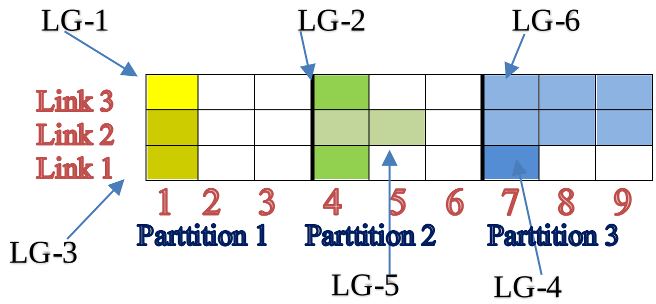
where each vertex is represented as a lightpath group. If two lightpath groups share one or more common links, an edge is established between the two vertices of the auxiliary graph.

Thereafter, we solve the graph coloring problem to determine the number of partitions, see Typically, the number of used colors should be equal to the number of partitions. As shown below-

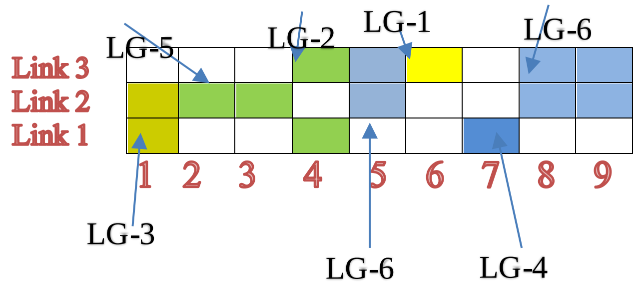


No. of colors = No. of partitions = 3

Thus, the entire spectrum is divided into three partitions and lightpath requests are allocated into those partitions according to the same color, which are shown below-



Below shows the spectrum allocation of lightpath requests without considering the dedicated partitioning approach.



Lightpath group graph transformation Algorithm: -

Input: *All lightpath groups in the network*
Output: *Lightpath group graph*

Step 1: Initialize these to f vertices *V* = f; g and the set of edges *E* = f; g.
Step 2: Vertex generation: Generate vertex *v* that corresponds to each lightpath group per unit slot demand, where *v* = 1;2; _ __ ; j *V* j for j *V* j paths, and then add *v* to *V*.
Step 3: Edge establishment: Establish edge (*v*, *u*) between *v* 2*V* and *u* 2*V* if the two light path groups corresponding to vertices *v* and *u* share at least one link, add(*v*, *u*) to *E*.

Above Algorithm shows the procedure used to create the lightpath group graph. The lightpath group transformation partition is described as follows. The route of each lightpath group is assumed to be given. A vertex of the lightpath group graph corresponds to a lightpath group per unit slot demand. For an example, a lightpath group that has two units slot demands, yields two vertices. If two light- path groups share a common link or more links, an edge is established between the two vertices. By default, vertices that correspond to the same lightpath group are connected by edge(s).

Largest degree first (LDF) Algorithm: -

Step 1: Select the uncolored vertex with the largest degree.
Step 2: Choose the minimum indexed color from the colors that are not used by adjacent vertices.
Step 3: Color the selected vertex using the color described in step2.
Step 4: If all the vertices are colored, LDF stops. Otherwise, LDF returns to step 1.

2.1.1.2 Multi-path Routing Approaches

To reduce the effect of bandwidth fragmentation, various online service provisioning algorithms were introduced by Zue et al. [26] which took into consideration dynamic routing, spectrum allocation with hybrid single-path routing or multi-path routing techniques, and modulation. They researched two categories of hybrid single-path or multi-path routing techniques for fixed path sets and online path computation by viewing various path selection policies in order to reduce bandwidth fragmentation and to maximize the network throughput so that the design is optimized.

R. Zhu, Y. Zhao and others [27] presented a spectrum allocation, multi-path fragmentation aware routing, and modulations technique for immediate and advance EONs reservation requests. A splitting scheme was introduced by the authors to solve the resource scarcity problem, in this scheme the request is split into multiple parts and these parts are then transferred onto one or more than one lightpaths with the help of sliceable bandwidth variable transponders.

To improvise the utilization of spectrum and in order to suppress fragmentation of bandwidth in EONS, Dharmaweera et al. [28] presented techniques for multipath routing and traffic grooming. In this work they first researched the possible gains by the joint application of practical model which takes into consideration physical impairments. The gains in effectiveness of spectral utilization were measured over existing methods.

2.1.1.3 Multi-Graph Approaches

A multigraph shortest path (MGSP) algorithm was introduced by Moura et al. [29] which suppresses the blocking ratio in EONs. The decision of allocation in MSGP algorithm were based on cost functions which try to capture the capability of spectrum fragments of allocating the incoming lighpath requests. It was observed by Moura that the MSGP algorithm decreases the bandwidth blocking ratio to 4 times in comparison to existing considered RSA algorithms.

2.1.2 Defragmentation Approach

This approach is considered to fill-in the gaps left behind after terminating a lightpaths. These approaches are classified into two main types: proactive and reactive. When a new lightpath request arrives in the network reactive defragmentation approaches are normally triggered. On the other hand, we can apply proactive defragmentation approaches without waiting for a new lightpath requests. Proactive and reactive defragmentation approaches are classified into two types, which is namely with and without rerouting of existing lightpaths. In order to avoid the fragmentation effect, The rerouting approaches [30, 31] reallocate existing lightpaths to the same or different spectrum slots by changing their routes. On the other hand, without rerouting, approaches do not allow existing lightpaths to change their routes; spectrum re-allocation may be allowed. On a basis of traffic disruption, both with and without rerouting of existing lightpaths are classified into the non-hitless and hitless defragmentation approaches, which are discussed below-

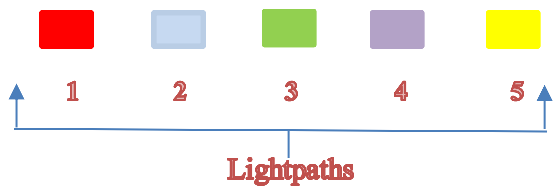
2.1.2.1 Non-hitless defragmentation approaches

Non- hitless defragmentation approaches attempt to maximize the size of contiguous blocks of unassigned frequency resources with triggering traffic disturbance. they are not preferred in EONs, because of these approaches always cause traffic disruption, To overcome this problem we have hitless defragmentation approaches, which is considered for EONs, as is explained below-

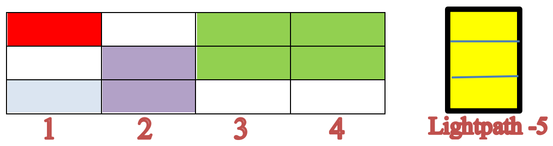
2.1.2.2 Hitless defragmentation approaches

Hitless defragmentation approaches is a techniques [32] attempt to maximize the size of contiguous blocks of unassigned frequency resources without triggering any traffic disturbance.

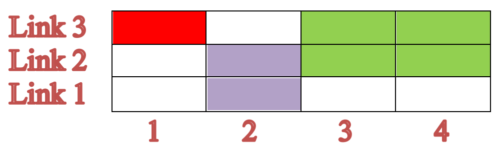
Example: -



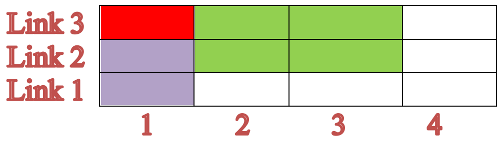
Suppose there are five light paths, which represented here by using different color of rectangular boxes.



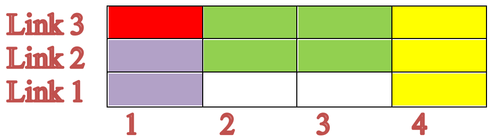
Here only four light paths are active, and fifth light path is not getting space in spectrum so by help of hitless defragmentation we actually allocate fifth light path into spectrum.



Form above diagram we are getting that lightpath 2 is terminated. Now and we apply hitless defragmentation to retune lightpaths 3 and 4. As shown in below diagram-



Finally, we can add lightpath 5 to the network in spectrum.



From the above diagram we can see 5th light path is also allocated and fragmentation is minimized also.

3. CONCLUSION

This paper deals with various methods to avoid spectrum fragmentation in Elastic Optical Networks before the allocation of spectrums to a connection request, i.e, non-defragmentation and along with that various methods to retune spectrum fragmentation that occurs after spectrum slots have been allocated to the lightpath request and results in portions of spectrum not being utilized to the full extent, i.e., defragmentation. Many methods regarding both the approaches have been discussed along with research done on them and various algorithms for the implementation of the same. Along with these we've presented our own views on possible techniques to minimize fragmentation efficiently.

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