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Efficient Spectrum Allocation with Survivability Technique in Elastic Optical Networks

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Abstract

In recent years, traffic requirement with variable bit rates and Quality of Service due to online High Definition video streaming, downloading movies and transferring of files are being satisfied with Elastic Optical Network (EON). Most efficient spectrum utilization is required to satisfy the demand with minimum blocking probability. The network is unstable and a small failure can lead to tremendous loss of data, hence survivability is mandatory. Slot Capacity based Spectrum Allocation with Survivability (SCSAS) algorithm is proposed which aims at the efficient spectrum utilization and configuration of protection paths. Duty Cycle Division Multiplexing (DCDM) and hop based modulation technique are also introduced to manage the spectrum which further reduces the spectrum wastage. The formation of spectrum fragments on the termination of existing requests increases the blocking probability. In order to improve the spectrum utilization, a spectrum defragmentation technique is introduced in the proposed work. Dynamic configuration of backup paths provides survivability. Results show an increase in free spectrum for dynamic requests, lesser spectrum wastage, and reduced blocking probability than the traditional algorithms such as fixed, flexible and random spectrum allocation.

Keywords*: Elastic Optical Network, Spectrum Allocation, Modulation, Duty Cycle Division Multiplexing, Spectrum Defragmentation, Survivability.*

1. Introduction

The growth in network usage demands large volumes of data transfer due to increase in network users. Spectrum is being a limited and an expensive resource and efficient spectrum allocation has to be done over the network for each request.

This paper [1] provides a Path Computation Element (PCE) architecture for EON to maximize the spectral efficiency. An adaptive spectrum control defragmentation technique was proposed in [2] to reduce the blocking probability created by the spectral fragments when requests terminate. Spectrum Expansion/Contraction (SEC) policy for modifying the spectrum allocated to each connection enables the dynamic sharing of

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spectrum slots among spectrum-adjacent connections was mentioned in [3-4] Spectrum efficiency was calculated by allocating a minimum utilized spectrum to a given set of demands. Modulation formats were discussed in [5] which has an impact on the spectrum efficiency. [6] DCDM was suggested for improved traffic grooming over optical networks to obtain larger spectral efficiency. The paper [7] dealt in limiting the connection sizes to obtain gain at the cost of losing some flexibility in EON. Various Modulation techniques were analyzed and compared in [8]. Elastic spectrum allocation for dynamic traffic load was discussed in [9].

Nowadays, multi-billion-dollar business transactions and critical surgical guidance are performed through the network. Thus, uninterrupted transfer of data is highly necessary. [10-11] dealt about the use of multiple paths to improve the throughput and reduce the blocking probability. [12] used shared backup path protection scheme and with a limited tuning range of a transponder, the Bandwidth Blocking Probability is reduced and spectrum efficiency is improved. [13] Proposed the use of Failure-Independent Path Protection p-cycle (FIPP p-cycle) to assign the protection paths in order to provide survivability.

In this paper, Slot Capacity based Spectrum Allocation with Survivability (SCSAS) technique is proposed which deals with effective spectrum management and also ensures survivability. Objectives of the proposed work is to efficiently allocate spectrum which reduces blocking probability, improves spectrum utilization and provides continuous transfer of data even in the case of failures. Section 2 describes the proposed work. Section 3 explains the Slot Capacity based Spectrum Allocation with Survivability (SCSAS) algorithm. Section 4 shows the simulation results.

1. Proposed Work

The challenging task for the networks providers are the efficient spectrum management and resolving network failures. These two challenging factors are considered in this proposed work to improve the spectrum allocation for sporadic request. Spectrum defragmentation, Modulation and DCDM techniques are also introduced in the proposed technique.

1.1 Spectrum Defragmentation

Spectrum fragments are combined for effective spectrum utilization by the process of spectrum defragmentation. When connections get torn down spectrum fragments occur, which increases the blocking probability limiting the maximum traffic load that can be accommodated by the network. Spectrum defragmentation can be a proactive or reactive response. Proactive defragmentation takes place when irrespective of the connection demand occurs whereas, reactive defragmentation occurs when the new request would get blocked otherwise. Hop tuning is a proven technique among spectrum defragmentation methods. Even though proactive defragmentation technique provides better spectrum utilization it leads to unnecessary shifting of spectrum slots. Below is an example where a new request of bandwidth B_1 = 25 GHz is to be allocated in the available existing spectrum of Figure 1.

Figure 1. Available Existing Spectrum

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Empty slot fragments are created when connection requests get terminated. Figure 2 explains proactive spectrum defragmentation. Figure 3 shows how the spectrum is allocated for the request in reactive spectrum defragmentation technique.

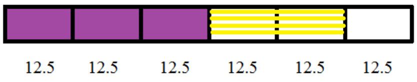

Figure 2. Proactive Spectrum Defragmentation.

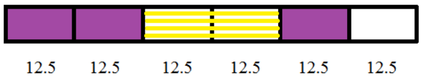

Figure 3. Reactive Spectrum Defragmentation

Reactive spectrum defragmentation response process is followed in the proposed work on the necessary basis.

2.2 Survivability

Small failure in a large amount of data transfer can cause a huge amount of data loss. Thus, survivability is introduced to ensure continuous transfer of data even in the case of failure which is the present research area in optical networks. Even though there are many reasons for the failure of data connection such as switches, fibers, transceivers, link and so on, link failure is considered as the most common cause of network failure among these. When there is single link failure, two types of protection mechanisms can be followed. They are Link based protection and Path based protection mechanism. An example of 6 node architecture in the following figure shows the differences in the protection mechanisms.

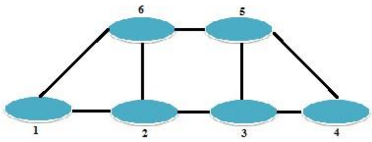

Figure 4. Six Node Architecture

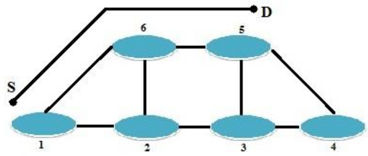

Figure 5. Transmission from Node 1 to 5

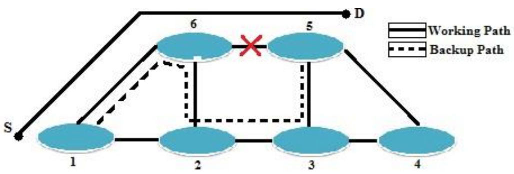

Figure 6. Link Based Protection

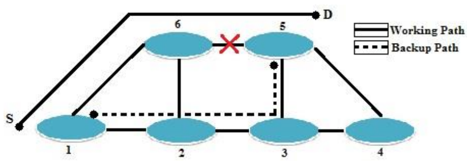

Figure 7. Path Based Protection

In link-based protection technique, only failed link is avoided in the working path, whereas in path-based protection technique the entire path where the link has failed is rejected. Generally, these protection paths can be configured during the configuration time of working paths (Proactive) or after the failure has occurred (Reactive). When compared to the reactive response, the proactive method of configuring the protection path during the working path assignment is advantageous as the delay in configuring the backup path and finding the necessary spectrum can be reduced. This provides a cost and time effective edge over the reactive response. The protection path ensures the continuous transfer of data even in the case of failures.

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1.2 Modulation & Multiplexing

Modulation & Multiplexing techniques play a major role to increase the transmission capability and bandwidth efficiency. DP – QPSK modulation technique is considered for longer distance (multi-hop) transmission as it provides a higher transmission reach and a higher bit rate. DP – 64 QAM modulation technique is selected for short distance (single hop) transmission which can transmit 64 bits in a symbol but only for a shorter distance. DCDM supports higher bit rates than other multiplexing technique and also provides a multi carrier modulation system. It is explained by the following figure.

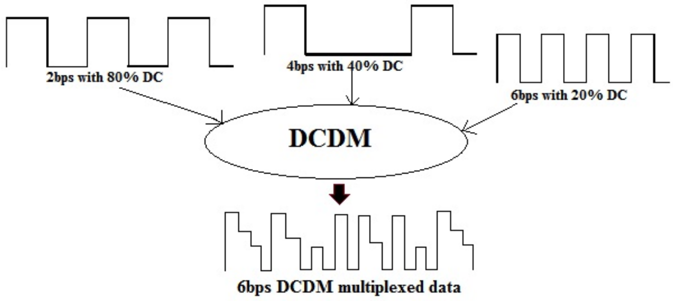

Figure 8. Duty Cycle Division Multiplexing

2. Algorithm

Received dynamic requests are gathered at a time interval T. Based on the hop count to the destination the requests are separated as single hop request and multiple hop request. Single hop request is modulated using DP-QPSK whereas multiple hop requests are modulated using 64 DP-QAM modulation format. The path is computed using the Dijkstra's k-shortest path algorithm. The first shortest path is selected as the working path and the second shortest path is selected as the backup path. Once the path is computed DCDM is performed. For spectrum allocation Slot Capacity Spectrum Allocation (SCSA) algorithm is followed. Figure 9 provides the SCSAS flow chart of the proposed work.

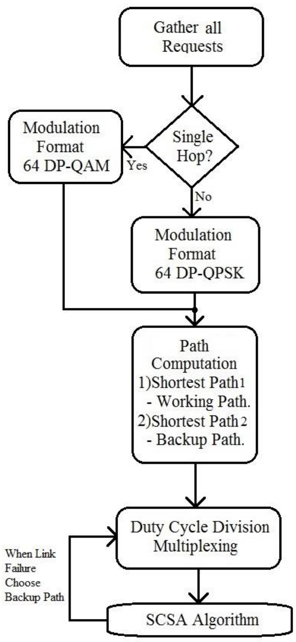

Figure 9. SCSAS Algorithm Flow Chart

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Notations

Request, $r_i = \{s_i, d_i, b_i, th_i\}$

Where,

s_i = source

d_i = destination

b_i = bandwidth demand

th_i= holding time

Fs_i= Free slot capacity

Fs_{th} = Free slot min. threshold value (75% of Fs_i)

Fs_n = Free slot max. threshold value (90% of Fs_i)

Slot Capacity Based Spectrum Assignment (SCSA) Algorithm

Spectrum Allocation is followed by SCSA algorithm. Constraint 1 is to be satisfied for the requests to be allotted to that spectrum slot. Spectrum wastage is reduced when constraint 2 is satisfied.

Constraint 1: $Fs_{th} \leq b_i \leq Fs_i \rightarrow$ Bandwidth should be within the minimum threshold value and full capacity of Fs.

Constraint 2: $Fs_{th} \leq b_i \leq Fs_n \rightarrow$ Bandwidth should be within the minimum threshold value and maximum threshold value.

The SCSA algorithm has three sub-modules.

- Direct fit: Under direct fit module, the request is assigned to that Fs_i slot if constraint 1is satisfied. If constraint 2 is fulfilled, $Fs_{(i+1)} = Fs_{(i+1)} + (Fs_i - b_i)$ is executed for efficient spectrum usage.

- Neighborhood selection: The neighborhood selection is performed when bi cannot be fitted into a single Fs_i. In this module, the first three neighbors of Fs_i are verified. i.e. $\sum_{i=1}^{3} Fs_i$ and is performed in three steps (i.e single neighbor fit, two neighbor fit, three neighbor fit) depending upon the bandwidth requirement.

- Hop tuning: When an allocation cannot be performed in both the modules, then ri is held in the buffer for time t. If the constraint could not be satisfied within the buffer time, then hop tuning is performed.

Algorithm

```
//Direct fit
If Fs_ith ≤ b_i ≤ Fs_i
        Allocate Fs_i to r_i
        IfFs_ith ≤ b_i ≤ Fs_n
                Fs_(i+1) = Fs_(i+1) + (Fs_i – b_i)
        end
 Else if b_i<Fs_th && b_i>Fs_i
        Check till third order neighbor ∑_{i=1}^{3} Fs_i
 // Neighborhood selection
 If Fs_neith ≤ b_i ≤ Fs_nei
                Allocate r_i to Fs_nei
                IfFs_neith ≤ b_i ≤ Fs_nein
                        Fs_(nei+1) = Fs_(nei+1) + (Fs_nei– b_i)
                end
        Else
```

Wait in buffer for t
If buffer > t
Check till third order neighbor $\sum_{n=1}^{3} Fs_n$
If $Fs_{nith} \leq b_i \leq Fs_{ni}$
Allocate Fs_{ni} to r_i
If $Fs_{nith} \leq b_i \leq Fs_{nin}$
$Fs_{(ni+1)} = Fs_{(ni+1)} + (Fs_{ni} - b_i)$
end

Else if bi>Fs_{ni}
If $Fs_i + Fs_{ni} \geq b_i$
Allocate bi to Fs_i and Fs_{ni}
If$Fs_{nith} \leq b_i \leq Fs_{nin}$
$Fs_{(ni+1)} = Fs_{(ni+1)} + (Fs_{ni} - b_i)$
end
Else if $Fs_i + Fs_{ni} \leq b_i$
$a = b_i - Fs_i$
$Fs_{ni} = Fs_{ni} - a$
$Fs_i = Fs_i + a$
Allocate b_i to Fs_i
End
end
If $b_i > Fs_i + Fs_{ni}$
If $Fs_i + Fs_{ni} + Fs_{(ni+1)} > b_i$
If $(Fs_i + Fs_{ni} + Fs_{(ni+1))th} \leq b_i \leq Fs_i + Fs_{ni} + Fs_{(ni+1)}$
Allocate bi to $Fs_i + Fs_{ni} + Fs_{(ni+1)}$
If $(Fs_i + Fs_{ni} + Fs_{(ni+1))th} \leq b_i \leq (Fs_i + Fs_{ni} + Fs_{(ni+1)})_n$
Add the remaining free spectrum to the $Fs_{(ni+2)}$
End
End
End
End
//When direct fit and neighborhood selection fails
Wait in buffer for time t
when time > t
Perform direct fit and neighborhood selection
End
//Even after buffer time request can't be allocated, then
//Check for free slots in neighborhood (Fs_{hp})
$Fs_{(i+1)}$ = temp
$Fs_{(i+1)} = Fs_{(hp)}$
$Fs_{(hp)}$ = temp
Perform neighborhood selection
//if it can't be allocated then
Reject r_i
end
Else
Reject r_i
End
End
End

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3. Results Analysis

Numbers of simulations have been performed to analyze the SCSAS technique. Spectrum Utilization, Spectrum wastage and spectrum free for future allocation is compared with traditional techniques. Dynamic requests with sporadic source and destinations have generated on bidirectional links. Requests are grouped together on timely basis. A request is given as R = [source (S), destination (D), bandwidth (B), and holding time (T_H)]. Dijkstra's K shortest path algorithm is used to find the shortest paths. For explanation of the technique a set of requests are considered in Table 1.

The spectrum for allocation is as performed on the slots available in figure 10. The slots are of equal capacity initially. Requests arrive at regular time intervals. Requests arrived at time T_1 are prioritized based on the free slot capacity. Slot allocation is from left to right. B11value lies is in between Fs_i & Fs_{th}, thus Fs_i is allocated to R_{11}. $Fs_{(i+1)}$ is modified to $Fs_{(i+1)} = (Fs_i – B_{11}) + Fs_{(i+1),}$ as $B_{11}<Fs_n$ which now fits B_{12} (R_{12}). $Fs_{(i+2)}$ is modified so that R_{13} is directly allocated. Fig.11 represents the spectrum allocation for all the requests arrived at T_1. T_H for R_{11} and R_{13} are < T as in figure 12, so once the requests get tear downed the corresponding slots are given precedence for future allocation. To meet the demand of R_{21}, the slots Fs_i and $Fs_{(i+2)}$ can be combined. Spectrum defragmentation technique and Hop tuning is performed. The slots $Fs_{(i+1)}$ and $Fs_{(i+2)}$ are switched. R_{21} is allocated with hop tuning technique as given in Figure 13. Neighborhood selection method is followed and by combining three neighborhood slots to satisfy R_{22}. Ahead of the next time interval, all the requests get tear downed due to T_H and normal slot prioritization of left to right is followed.

Table 1. Connection Requests in the Time Intervals $t_1$and t_2.

Time(T)	R	S	D	B	T_H
T_1	R_{11}	1	4	14	8
	R_{12}	2	6	9	15
	R_{13}	6	5	14.5	7
T_2	R_{21}	3	2	28.5	4
	R_{22}	4	5	37.5	9

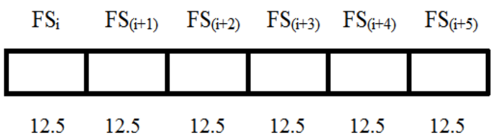

Figure 10. Empty Slots Available for Allocation

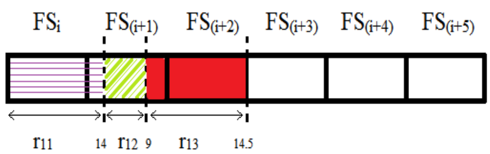

Figure 11. Spectrum Allocated at T_1

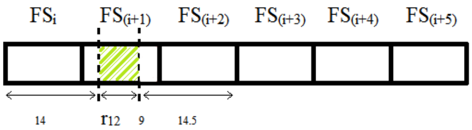

Figure 12. Spectrum Available for T_2

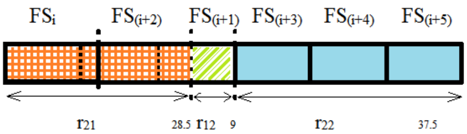

Figure 13. Spectrum Allocated for T_2 Requests

Pre-computing of backup paths provides survivability and reduces time delay to configure paths during link failures. The traditional techniques such as Fixed, Flexible and Random Spectrum allocation are used for comparison for a load of ten, twenty, thirty and forty dynamic requests. Figure 14 shows the Spectrum Free comparison within the techniques for the different loads. In Fixed technique, the spectrum allocation is followed from left to right. It follows direct allocation and thus it has a lower amount of spectrum free for future allocation. Flexible technique performs contraction and expansion along with direct fit allocation method so that more spectrum will be free for future allocation that results reducing blocking probability. Random technique allocates spectrum by selecting slots randomly. This leads to efficient spectrum usage but with higher risks. Blocking probability is lesser than fixed technique but when compared with the flexible technique it can’t be predicted accurately. SCSAS technique as explained above with an example performs better allocation with the combination of direct fit, neighborhood selection and hop tuning methods. The free spectrum is the spectrum that can be used for future allocation. We can see better spectrum usage which increases spectrum free for upcoming demands. The blocking probability is reduced and improved spectrum utilization is experienced.

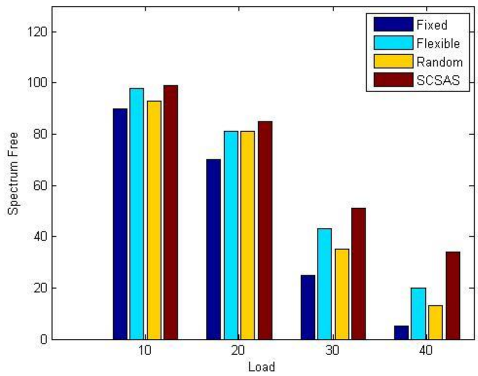

Figure 14. Spectrum Free Vs Load

The spectrum is used for the corresponding loads are shown in Figure 15. The efficient spectrum usage is witnessed in SCSAS technique by proper utilization and selection of slots for allocation. The hop tuning method improves the spectrum utilization and provides efficient use of spectrum for the requests. The choice of up to three neighbors is limited so as to keep the time consumed for allocation under check.

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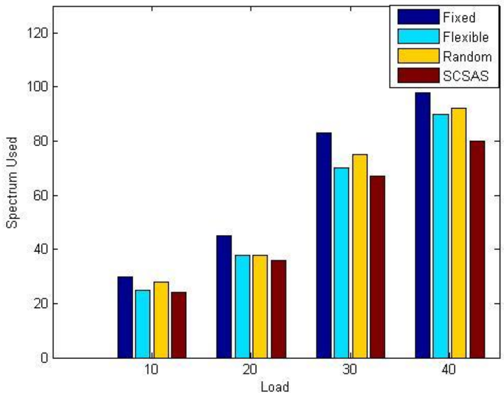

Figure 15. Spectrum Used Vs Load

Spectrum Wastage of the techniques for the corresponding loads is compared in Figure 16. Wastage of spectrum occurs when spectrum becomes unavailable for any other request allocation. The fixed technique shows more spectrum wastage than other techniques as it does not follow any flexibility and the remaining spectrum gets wasted. The flexible technique has flexibility methods to reduce spectrum wastage. Random technique has higher chances of lower spectrum wastage than flexible technique. SCSAS by efficient spectrum allocation results in reduced spectrum wastage than other techniques.

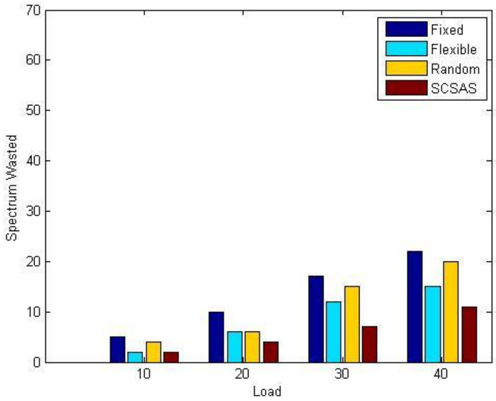

Figure 16. Spectrum Wasted Vs Load

4. Conclusion

In recent years, due to varied bit rate and floating bandwidth requirement, effective Spectrum management is a challenging task more over network failure is also a major problem for the network providers. The proposed technique provides effective solution by including DP-QPSK and DP-64 QAM modulation, DCDM, Survivability and SCSA algorithm. Simulation result shows an increased free spectrum availability with least spectrum utilization and spectrum wastage when compared with the traditional techniques for various traffic loads. The improved availability of free spectrum enhances the acceptance rate for future requests. The SCSAS technique also guarantees continuous transfer of data by pre-computing the protection paths for survivability in EON. In future, effective energy management is to be included in SCSAS technique which is a vital consideration for reducing power consumption in the optical networks.

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