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RESEARCH ARTICLE

DYNAMIC MULTICAST SPECTRUM (Re) ALLOCATION USING SHARED BACKUP PATH IN ELASTIC OPTICAL NETWORKS

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Abstract

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The routing and spectrum allocation (RSA) problem in elastic optical networks (EON) is to first find a path for a connection request and then allocate a frequency slot to it. Due to spectrum continuity and contiguity constraints, some available frequency slots cannot be allocated to connection requests. In this case, one solution is to reassign slot to some existing connections to accept new ones. However, most current reallocation schemes are proposed for unprotected connections. With the very high throughput of connections in EONs (Tb/s per link), the requirement for connection protection is becoming standard. In this paper, we examine a frequency slot reallocation approach for protected multicast connections. The proposed approach allows the reallocation of available and already used slots by temporarily using the protection resources. The experimental results show an average blocking probability of 10% lower than reallocation with hoptuning and the conventional MC-RSA algorithm.

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Introduction:-

Context

Elastic Optical Networks (EON) represent one of the major solutions to cope with the heterogeneous nature of today's bandwidth demands. In these networks, the spectrum in a link is subdivided into small units called Frequency Slots (FS) identified by a specific index number. This feature of EONs allows for dynamic and flexible allocation of bandwidth (block of slots) according to user demand. However, spectrum allocation in EONs is subject to two main constraints, namely contiguity and continuity of spectrum. These constraints make spectrum allocation in EONs complex. The problem of route selection and spectrum allocation in EONs is called Routing and Spectrum Allocation (RSA) problem [1]. The contiguity constraint means that the FSs assigned to a connection must be contiguous (successive indices). The continuity constraint requires that for a given connection, the same spectrum range (the same successive indices) is reserved in each link along the connection path i.e. from source to destination. Many applications in optical networks require the transmission of identical data from a network node called the source to several other network nodes called destinations [2]. The connection from a single source to several destinations is

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called a multicast connection. This type of point-to-multipoint connection is realised in optical networks through a ligth-tree. An optical tree can be thought of as a tree rooted at the source node where the leaf nodes of the tree are the destinations. In this context, each path from the source to the destination of a multicast tree is called a branch of the optical tree. There are different ways of dealing with the spectrum allocation of connections, while some only allocate a connection request if there are contiguous slots available, others try to reallocate existing connections to make room for new requests. Regardless of the allocation scheme used, protection methods are regularly included to allow for greater reliability of EONs [3][4]. This involves reserving alternative paths in the network for each branch of the tree that will be used in the event of a physical link failure on one of the branches of the multicast tree to replace it. With the number of resources available to protect current connections, shared backup path protection methods (SBPP) are preferred by operators over dedicated backup path protection (DBPP). In this protection method, some backup paths of the branches of the multicast tree can share the same protection resources (links, slots), as long as the branches they protect are of disjoint link. Continuity and spectrum adjacency constraints are one of the main causes of blocking connections in EONs. A reallocation of slots with established connections can create blocks of contiguous slots to satisfy ongoing requests.

Objectifs:-

The objective of this paper is to reduce the probability of blocking in the network. Specifically, we need to: propose a slot reallocation mechanism for established multicast connections using temporary backup paths.

Motivation

Many dynamic reallocation approaches have been proposed [8][9][10][11][12]. These approaches consist in reallocating only available resources to already established connections in order to accept new requests. In elastic optical networks where the connections are not protected, these techniques reduce the probability. However, in elastic optical networks where connections are protected the probability can be improved by reallocating available or already used slots to existing connections. This is possible by using the resources of the backup paths without interrupting the already established connections.

Oganization

The rest of the paper is organised as follows in 2 we will have the state of the art on routing and spectrum assignment, as well as on reallocation, Section 3 presents a formal definition of the problem of reallocation of multicast connections using backup paths. Section 4 proposes the Shared Backup Path Protection Reallocation (***SBPPR)*** algorithm. In Section 5, the proposed algorithm is simulated and the results are analysed and discussed. Finally, Section 5 concludes with some perspectives.

Related Works:-

Multicast routing and spectrum allocation with shared backup paths

In this section, we present the basic approach to multicast routing and spectrum allocation (MC-RSA). This approach consists in splitting the routing and spectrum allocation problem into two sub-problems. The first is the routing problem, which consists of finding a tree for a given connection request. The second problem is spectrum allocation, which seeks available spectrum resources for the request according to the contiguity and continuity constraints mentioned above. Thus for each multicast connection request, k disjoint shortest path trees are pre-computed, then we sort the list of the k shortest paths obtained in the order they were found. We select the first tree as the route of the connection request if it can be allocated, the disjoint backup paths of the tree are calculated for each branch of the tree. Finally we reserve the resources for each of the obtained backup paths. If the first tree cannot be allocated and/or the backup paths found, we try the next tree among the k trees, and the process stops when the tree and the backup paths can be allocated or if we have tried all k trees [12][14].

Spectrum reallocation

When the selected tree and its backup paths are allocated, the multicast connection request is established in the network which now has a number of contiguous slots to handle the traffic. Each connection request is allocated in the first available contiguous slots on all links in the tree. If there are enough slots available on the links in the tree, but the slots are not contiguous, we try to reallocate existing connections in order to create contiguous slots to satisfy the new connection request [15][16]. Several reallocation techniques exist and can be grouped into 4 main techniques [17].

The first is the re-optimisation technique, which consists of interrupting the current connection before re-establishing on new slots. This technique is energy efficient as no additional equipment is required. It is also the most efficient in terms of reallocation solutions, however, it causes a large number of flow interruptions (Figure 2). Because of the high number of interruptions it causes, it is often used for the reallocation of backup paths [32][33].

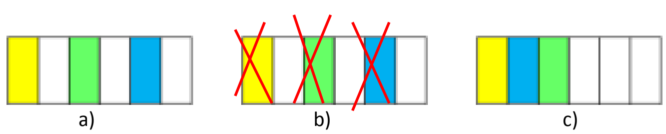
With the Make-Before-Break technique, the connection to be reconfigured is established on its new path before the old one is deleted. This avoids interruptions to the flow. However, the increased use of network resources required for its implementation is a major drawback (Figure 3). The MBB [18], MBBR [19] and MCDA [20] algorithms are an implementation of this technique. Most approaches implementing this technique are designed for unprotected networks. Due to the additional resources involved, reallocation solutions with the Make-Before-Break technique are limited by the availability of intrinsic network resources.

The push-and-pull technique initiated in [33][34] is a response to the resource wastage of the MBB technique. In this approach, the existing connection is moved into adjacent available slots of the same size, so that it becomes adjacent to another connection (Figure 2). In [24], [25], the authors presented algorithms that use reallocation and rerouting of existing connections with the *push-pull* technique. However, the trade-off of this technique to the increased use of additional resources is a long execution time. In addition, the proposed reallocation solutions are limited to the reallocation of available slots. Whereas already used slots can be reallocated if the connections using them are in turn reallocated first. In [26] and [27] the authors proposed reallocation schemes using dedicated backup paths. In this scheme, a backup path and its primary path are exchanged so that the backup path becomes the primary path and the primary path becomes the backup path. Such an approach is not viable for multicast connections where the exchange between a backup path and its primary path (in this case a branch of the multicast tree) may cause flow interruptions.

Finally the Hop-tuning technique in which, an existing connection is moved to any available contiguous slots. This hop-tuning is a great advantage, as the time required for such an operation is very short (Figure 4). In [22] the authors showed the efficiency of the hoptuning technique compared to the MBB and *push-pull* techniques. In [21], the authors proposed a reallocation algorithm with the *hop-tuning* technique that minimises the number of connections to be reconfigured in unprotected networks. The proposed approach reallocates only the available slots.

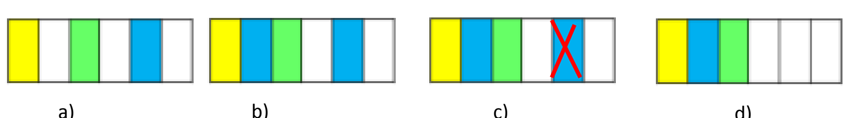
The body of work on slot reallocation in elastic optical networks only reallocates free slots in the network. This greatly limits the reallocation performance, so the use of backup paths can allow the reallocation of already used slots. We therefore propose to overcome the dependencies between already used slots by using backup paths in the reallocation process to increase the reallocation solutions of existing connections in order to reduce the probability of network blocking.

Image I:-



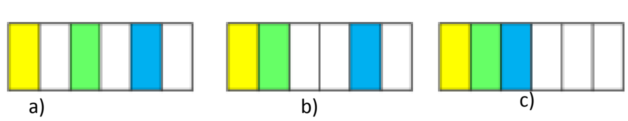
Reallocation by reoptimisation: a) network state before defragmentation, b) step 1: delete all current connections, c) step 2: restore all connections (network state after defragmentation).

Image II:-



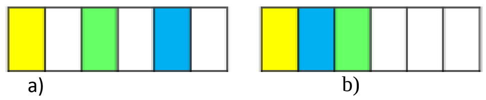
Reallocation by the Make-Before-Break method: a) Network state before defragmentation, b) step 1: create a copy of the existing connection in (blue), c) step 2: delete the original connection d) step 3: network state after defragmentation

Image III:-



Push-and-pull reallocation: a) Network state before defragmentation, b) step 1: move the green connection to the left, c) step 2: move the blue connection adjacent to the green connection (network state after defragmentation).

Image IV:-



Hop-tuning reallocation: a) Network state before defragmentation, b) Step 1: Move the blue connection between the yellow and green connections (network state after defragmentation)

Modelling the problem:-

Network Model

The network model we propose is as follows:

An EON network can be considered as a graph G = (V, E) where V = $\{v_i \mid i = \{1,2,\ldots,n\}\}$ is the set of vertices and E = $\{e_{ij} \mid i,j \in V\}$ is the set of links. A node v_i corresponds to a variable optical switch in the network and a link e_{ij} represents a fibre optic link. No wavelength conversion is allowed in the network and all nodes have multicast capability.

- Let F = $\{f_1, \ldots\ldots, f_{|F|},\}$ an ordered set of frequency slots where F represents the number of slots in each lin of the network.
- A multicast connection request $mc = \{s, D, n\}$ where s is the source node and D = $\{d_1 \ldots . d_n\}$ the set of destinations nodes of mc and n the number of slots requiered by mc.
- Let MC = $\{mc_i \mid i = 1, \ldots . k\}$ be the set of existing multicast connections in the network such that $mc_i = \{s_i, D_i, n_i\}$ where s_i is the source node D_i the of destinations nodes, and, n_i the number of slots assigned to mc_i.
- T = $\{T_1, \ldots, T_k\}$ the set of primary optical trees existing in the network where T_i is the primary tree associated with the multicast connection mc_i existing in the network.
- P'_d the backup path of the branch P_d of the tree T_i with source s and destination d.
- $\theta = \{g_i \ldots . g_n\}$ the set of emergency path groups.
- $g \in \theta$ / $g = \{\forall P'_d \in g / \cap P'_d \neq \emptyset\}$ a group of escape paths such that all escape paths belonging to **g** share the same protection resources (links and slots).

Problem formulation

The problem we are studying is formulated as follows:

Given: An EON network G (V, E), T = $\{T_i \mid T_i, \ldots, T_k\}$ the set of existing primary optical trees in the network such that T_i carries the flow of mc_i, $mc = \{s, D, n\}$: A connection request, T_c : the primary tree of the connection request mc, θ the set of backup path groups. S_0 : The initial state of the network.

Objectives:-

- Reduce blocking probability of the network.

Specific objectives:

- Determine the primary tree T_c for the demand mc
- Reallocate slots of existing connections adjacent to T_c if necessary to meet the mc demand using the backup paths if available.

Constraints:

- The initial routing of already established primary connections does not change
- The initial routing of the backup paths does not change.
- Reallocation carried out without interrupting flows.

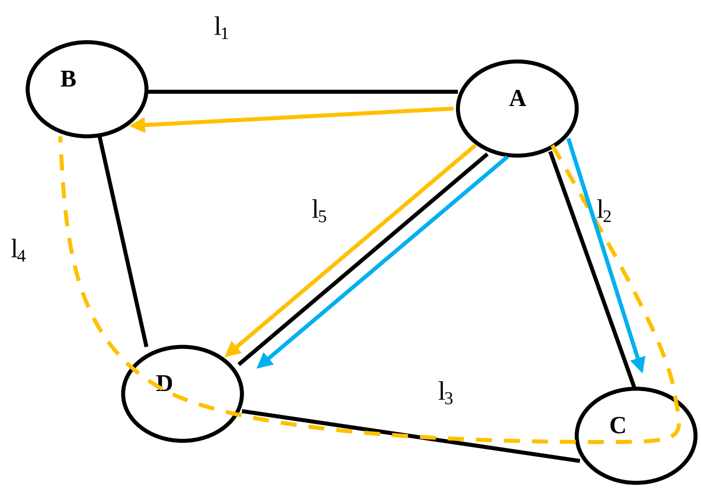
Problem specification

The current reallocation schemes only reallocate available slots of the links of the constructed tree for the connection request. Instead of reallocating only available slots, we propose here to reallocate also slots already used to build the primary tree for a connection request. This approach comes up against several obstacles. Firstly, this operation may cause a flow interruption if the private connection of these slots is not migrated to other slots before the reallocation. In the case where slots are not available for migration, the connection proposes to switch the flow of the primary tree to the backup paths of its branches temporarily to compensate for this interruption. However, this second step also poses a serious problem in that if the mechanism does not provide for available slots for the primary tree after the flow has been on the backup paths, it may result in a block. This blocking results in the impossibility of re-establishing the primary shaft in the network. Finally, the backup paths of a primary tree cannot be used as temporary paths as both (primary trees and backup paths) are not reconfigured at the same time. All the situations mentioned here make the problem of reallocation with backup paths difficult despite the availability of protection resources.

Proposed Method:-

An instance of the problem specified in 2.3 is illustrated in Figure 5. In this example we have a network with 4 nodes and 5 links. We have a multicast connection request from 2 slots of source A and destination C and D (*mc* = {A,{C,D}, 2}). Let us then assume that the primary tree chosen for the request *mc* is the tree T_c in blue. Table 1 shows the slot usage status in each link of the network at the time the request *mc* arrives. In the first row we have the slot indices. In the first column we have the links of the topology. Each colour corresponds to a primary tree already established and the hatched links of the same colour correspond to the links of the backup paths of the tree. The occupied slots are labelled so that each used slot is associated with the colour of the connection that uses it. In this example there are two slots available in the links l_5 and l_2 of the tree T_c. However, the exclusive reallocation of the available slots does not allow the primary tree T_c to be established.

Image V:-



Network with 4 nodes and 5 links

Table I:- Initial state of the network.

Links	**0**	**1**	**2**	**3**
l1	0	T1	T1	0
l2	T1	T1	0	0
l3	T1	T1	0	0
l4	T1	T1	0	0
l5	0	T1	T1	0

Table II:- Step 1: Switch the branches of T_1 to their backup paths, which ensures the continuity of flow from A to D and C.

Links	0	1	2	3
l1	0	0	0	0
l2	T1	T1	0	0
l3	T1	T1	0	0
l4	T1	T1	0	0
l5	0	0	0	0

Table III:- Step 2: Reallocation of slots (0,1) to tree T1 at this stage the resources released are sufficient to establish the tree Tc.

Links	0	1	2	3
l1	T1	T1	0	0
l2	T1	T1	0	0
l3	T1	T1	0	0
l4	T1	T1	0	0
l5	T1	T1	0	0

Table IV:-. Step 3: Establish the Tc tree on slots (2,3).

Links	0	1	2	3
l1	T1	T1	0	0
l2	T1	T1	0	0
l3	T1	T1	0	0
l4	T1	T1	0	0
l5	T1	T1	0	0

Algorithm heuristics

To address the reallocation deadlock in Figure 5, our approach is to first split the backup paths into groups so that all backup paths belonging to a group share the same resources. Here we obtain a single group of backup paths g_0 = {A-C-D and A-C-D-B}. Then for each link of the request Tc we determine the existing connections or the group of backup paths passing through this physical link. Here we obtain the$_2$: {g_0 }, the$_5$: {T_1 }. For each link of we reallocate on the lowest possible indices the existing connections and/or the group of backup paths which use this link. For the link l_2 the backup path group g_0 is already on the lowest indices here on slots (0,1). For the link l_5 it is necessary to reallocate T_1 to slots (0,1), but such a reallocation requires T_1 to be interrupted and then reallocated to these slots, since slot 1 is already occupied by the connection T_1 . To avoid this interruption in a first step, we switch the flow of the tree T_1 on the backup paths of its branches as in [23] (table 2). Then we delete T_1 (Table 2), before reallocating it to slots (0,1) in a second step (Table 3). In this way, we can free up resources for the primary tree Tc (Table 4). the remainder of the paper we refer to an existing optical primary tree already established in the network or a group of network backup paths. We then list **L** all the links in the primary tree of the application. For each link $l \in L$ we list List_Realloc the existing connections (primary optical tree and/or backup path group) that use this link (algorithm 2, line2). We then sort the connections in ascending order of the slot indices used (Algorithm 2, line 15). At this level, we have for each link an ordered number of existing connections to reconfigure. For each link *l* of L, we start by simultaneously switching all the optical trees of List_Réalloc to their backup paths as in [23]. Then we simultaneously free the slots of all the connections using this link (line 16 to line 21 Alg.2). These first two steps make it possible to avoid flow interruptions since, when the slots are released, the signal of the primary optical tree is transmitted by the backup paths and that of the backup paths by the corresponding primary trees. Then the first available contiguous slots are simultaneously reallocated in the order of **List_Realloc** for each List_Realloc connection. Once the connections have been reallocated, all the flows previously switched to their backup paths are restored to their respective primary trees. This process is repeated for each link and stops only when the primary tree of the request can be allocated or if all links have been processed.

Aglorithm I:- Multicast routing and Dynamic spectrum allocation with the use of backup paths

Input: Physical topology G graph G = (V, E), multicast request (s_c ,D_c ,n_c) A: list of k precomputed trees of (s_c ,D_c ,n_c).
Output: A protected multicast session (E_c , E'_c , S_c)

For a multicast session (s_c ,D_c ,n_c)
  While (n < k) do
    While $D_c \neq \emptyset$ **do**
      Select a destination $d \in D_c$
      If there is a path from s_c to d **then**
        Find the shortest path P_d from s_c to d (Dijkstra)
        Set $E_n = E_n \cup P_d$
        $D_c = D_c - \{d\}$
      End
    End
    Build the T-tree$_n$ with the links from E_n
    A = A ∪ T_n
    n = n + 1
  End
  Short A according to the smallest number of links
  While e < k do
    $T_c = T_1$ //considered T_1 as primary tree
    If the resources to establish T_c are available, in G - {T_c } **then**
      While $D_c \neq \emptyset$ **do**
        Select a destination $\in D_c$
        If a path from s_t to d exists **do**
          Find the shortest path P'_d from s_c to d such that $P'_d \cap P'_j \neq \emptyset$ as long as $P_d \cap P_j = \emptyset$
          Set $E'_c = E'_c \cup P'_d$
          $D_c = D_c - \{d\}$
        End
      End
      If we get back up path from the source to each of the destinations in D_c **then**
        If the resources to establish all the backup paths obtained are available **then**
          Establish the primary tree
          Establish all backup paths
          Accept the session (s_c ,D_c ,n_c)
        End
      Else
        e =e + 1
      End
    Else
      If (m <1)
        Run Algorithm 2
        m = m + 1
        Go to 18
      End
    End
    e = e + 1
  End
Dismissed the application (s_k ,D_k ,n_k **)**
End

Aglorithm II:- Reallocation with SBPP

Input: G = (E, V), C, T_k , (s_k ,D_k ,n_k), L , θ = {g_i ....g_n }

```
List_Realloc
Output: Rearrangement
While L≠ ∅ do
    Select a link  l ∈ L // Select a link
    While T ≠ ∅  do
        If T i ∩ l ≠ ∅
            List_Realloc = List_Realloc U Ti
        End
        T = T  \ {Ti}
    End
    While θ  ≠ ∅  do
        If gi ∩ l ≠ ∅
            List_Realloc = List_Realloc U gi
        End
        θ = θ  \ {gi}
    End
    Short this List_Realloc in ascending order of the first slot indices used
    If T i∈ List_Realloc then
        Switch Ti to T'i
    End
    If g i∈ List_Realloc then
        Free up reserved slots on gi
    End
    simultaneously reallocate the List_Réalloc connections in order.
    L= L {l}
End
```

Simulation and Performance:-

Simulation parameters

Our proposed backup path based reallocation approach (Algorithm II), the routing and allocation of protected optical trees incorporating spectrum reallocation with shared backup paths (Algorithm I) and reallocation without the use of backup paths are simulated on standard network topologies. These are the USA-Backbone and cost_239 physical network topologies. The simulations were performed using the FlexgridSim simulator [28]. The type of traffic request considered here is multicast: one source and several destinations. The connection requests are generated randomly according to a uniform distribution and each source node and the set of destination nodes of the request belong to the set V. Each fibre has a capacity of 150 FS and each slot is 12.5 GHz wide. The bandwidth requirement for each multicast traffic request is evenly distributed between 1 and 8 slots and the optical tree requests are established according to the first-fit approach. The inter-arrival time and the connection holding time are generated according to an exponential distribution [12]. For each network, between 500 and 1000 multicast connections are randomly generated with a number of destinations between 2 and 4. All nodes in the network have a multicast function. During the different simulations, no link break is allowed in the network operation. The simulation scenario is as follows: When a connection request arrives, we compute off-line all the trees of the most possible paths from the source to the different destinations in the Dijkstra algorithm (SPT). The resulting trees are sorted into a list as explained in 3.2.1. For our different simulations, we use the first two trees of the obtained list as candidates for demand routing to limit the computation time (k=2). If the resources to establish the first tree are not available, the SBPPR reallocation algorithm (see Algorithm 2) is used to find the resources, if it fails the second tree is chosen for routing. Following the allocation of the second tree, if the resources are not available, SBBPR is again triggered to find the resources to establish the second tree. If it fails again to find the resources, the connection is finally rejected. For each traffic load (Erlang) in each network, and for a number of connection requests (500 and 1000), 10 simulations are performed and an average blocking probability is calculated. The average fragmentation of the network links is calculated per period of 100 processed requests. Some of the key network simulation parameters are given in Table

Table V:-. Simulation Environment.

Parameters	Values	
Networks	COST 239	USA Backbone
Number of nodes	11	24
Number of links	26	43
Frequency Slots Units	12.5 Ghz	12.5 Ghz
Number of Slots per links	150	150
Type of Tree	SPT	SPT
Load (Erlang)	100 to 1000	100 to 1000
Number of simulations/ Load	10	10
Number of Slots per multicast session	1 to 8	1 to 8
Routing	Dynamic	Dynamic

Metrics

We evaluate the performance of our proposed approach with conventional MC-RSA, and the pathless reallocation with Hoptuning, only on two metrics:

- The Blocking Probability (BP) is defined as the ratio of the total number of blocked connection requests to the total number of requested connections. Let B be the number of blocked connection. R the number of connection requests and BP the probability of blocking:

$$BP = \frac{\sum_i^B T_i}{\sum_i^B T_j} \quad (1)$$

- Le The fragmentation rate makes it possible to assess the good distribution of slots in the network. The metric used here is Shanon's entropy [35]:

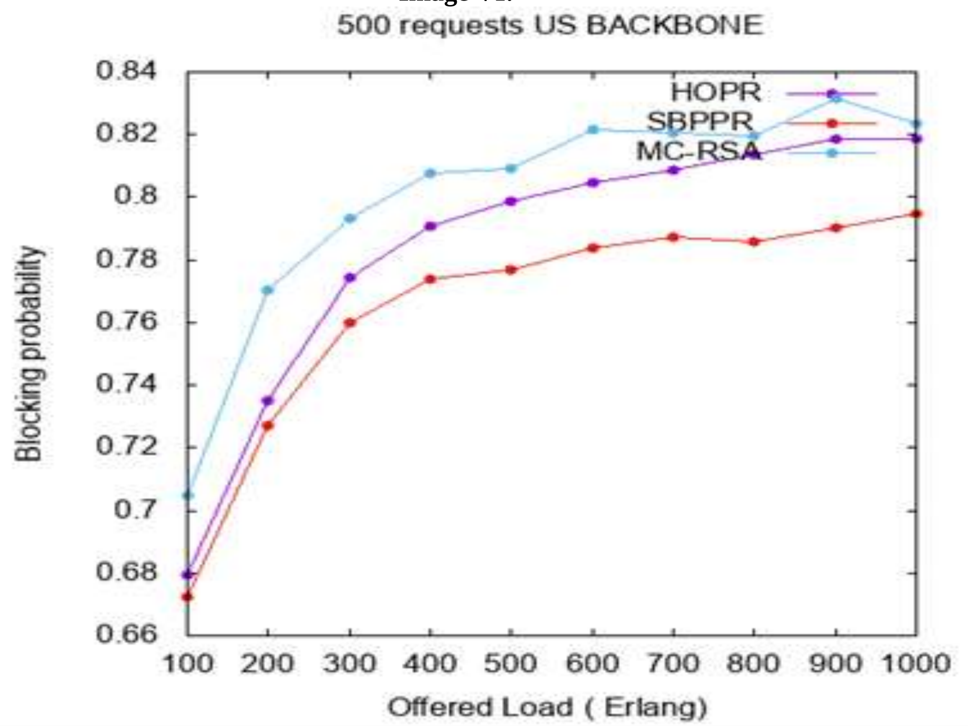
$$\sum_{i \in I} \frac{f_i}{S} \ln\left(\frac{S}{f_i}\right) \quad (2)$$

Where S is the number of slots in the network links and f_i a contiguous block of i slots.

Analysis of the results

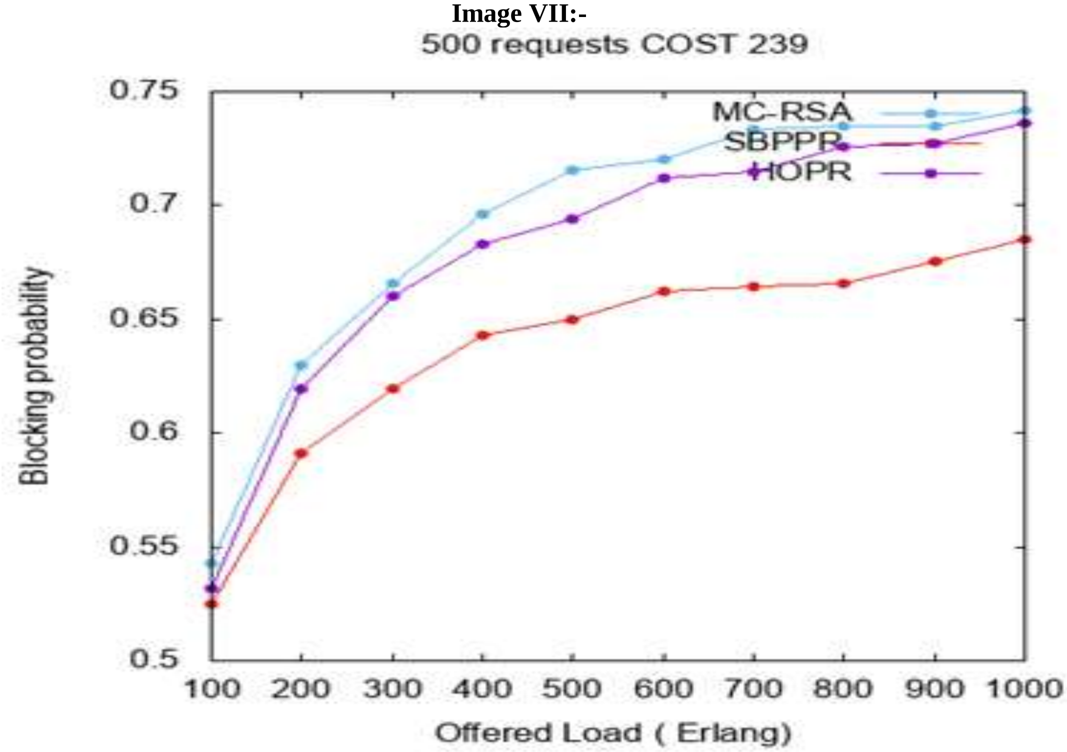
The results of the different simulations performed are shown in Figures 8, 9, 10, 11, 12, 13 and 14. Figures 8, 9, 10 and 11 show the blocking probability versus traffic load of each approach. For comparison purposes, we incorporate the results of the conventional MC-RSA scheme and the Hoptuning reallocation approach without the backup paths. Our proposed approach is named SBPPR, the standard multicast routing and spectrum assignment approach is named MC-RSA and the Hoptuning reallocation approach without backup paths is named HOPR. It can be seen that the blocking probability using the approach without reallocation is higher than that of the other two methods. It is also observed that the blocking probability of our proposed reallocation method (SBPPR) is lower than Hoptuning reallocation scheme without using escape paths (HOPR). The reason is that the HOPR approach only reallocates available slots in the network, whereas SBPPR reallocates both available and used slots. SBPPR therefore provides more reallocation solutions than the HOPR approach, which has a direct influence on the number of blocked connections. On average, SBPPR achieves a 10% lower blocking probability than the other two approaches when considering both networks. Figures 10, 11, 12 and 13 show that MC-RSA entropy is less of the network links. The analysis of this figures shows that the entropy of the network created by SBPPR is the highest followed by that of HOPR and finally MC-RSA. These entropy values correspond to the fragmentation of the network generated by different approaches. Thus, the lower the blocking probability, the higher the level of fragmentation generated. This spectrum fragmentation translates the repartition of the slots to the established connections of the network. The more connections there are the fewer slots there are to allocate. With variable bandwidth demands, the approach that accepts more connections results in higher network fragmentation.

Image VI:-



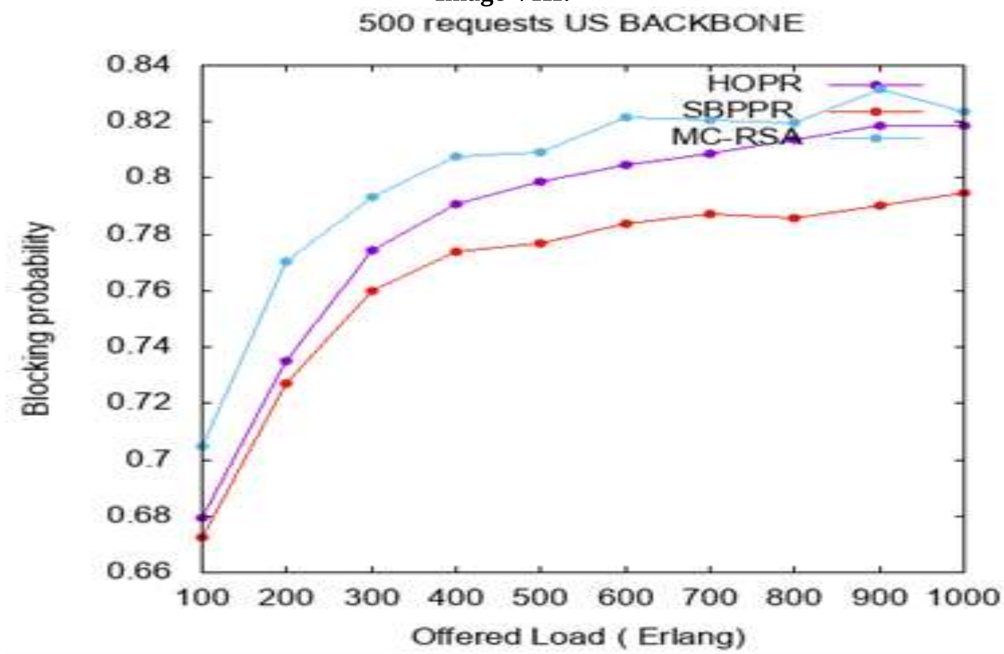
Probability of blocking with 500 queries on the COST 239 network

Image VII:-



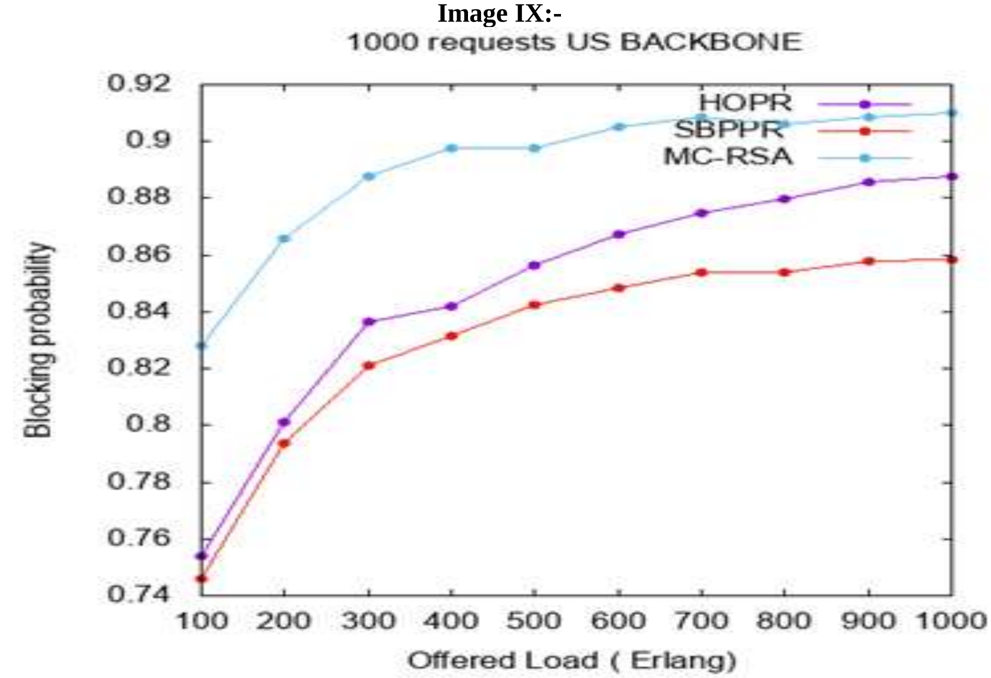
Probability of blocking with 1000 queries on the COST 239 network.

Image VIII:-



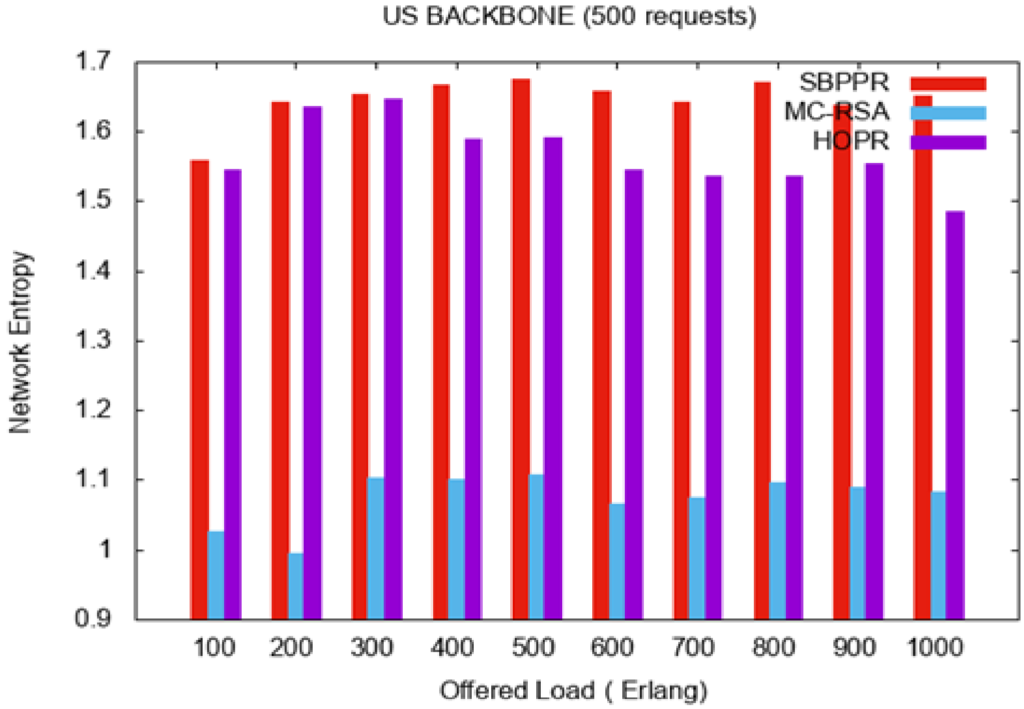
Probability of blocking with 500 requests on the USA Backbone.

Image IX:-



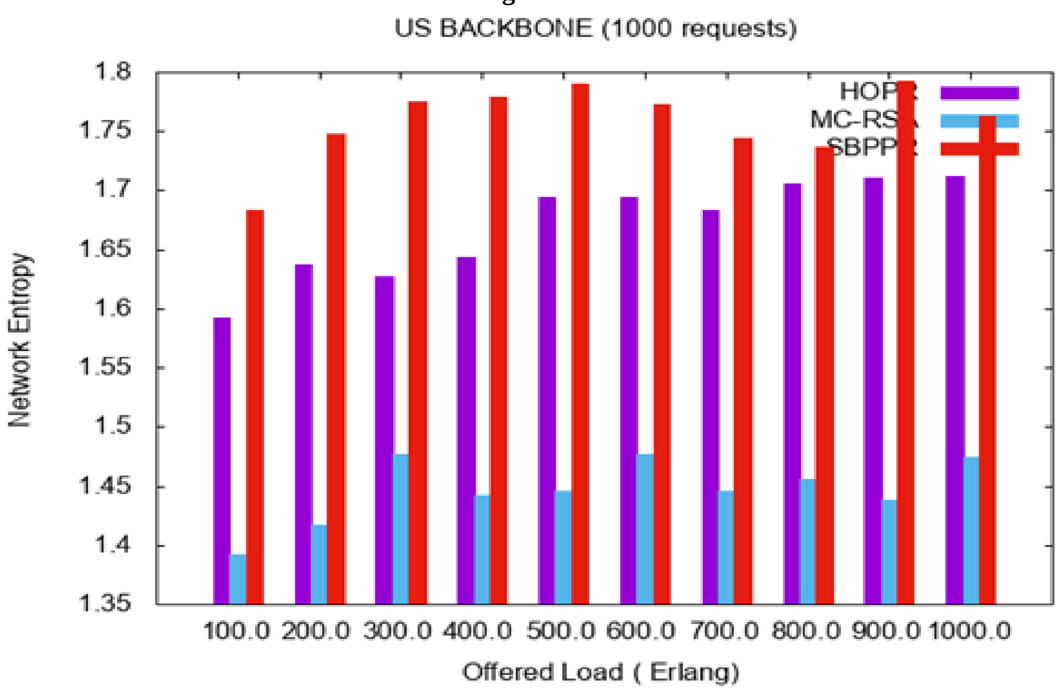
Probability of blocking with 1000 requests on the USA Backbone.

Image X:-



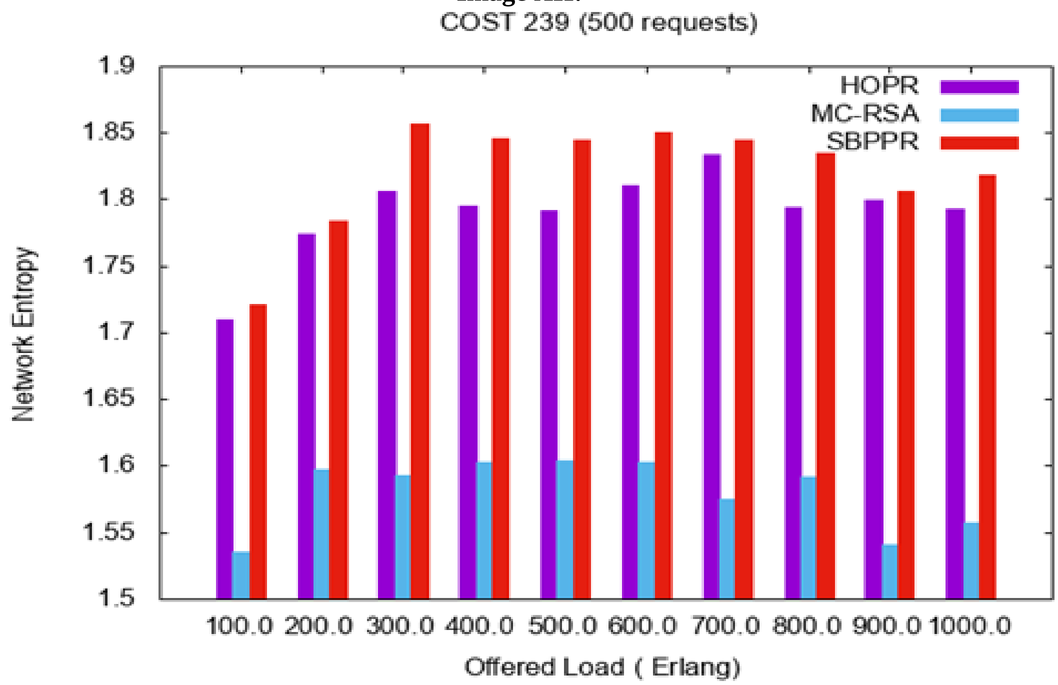
Networks Entropye 500 requests on US Backbone

Image XI:-



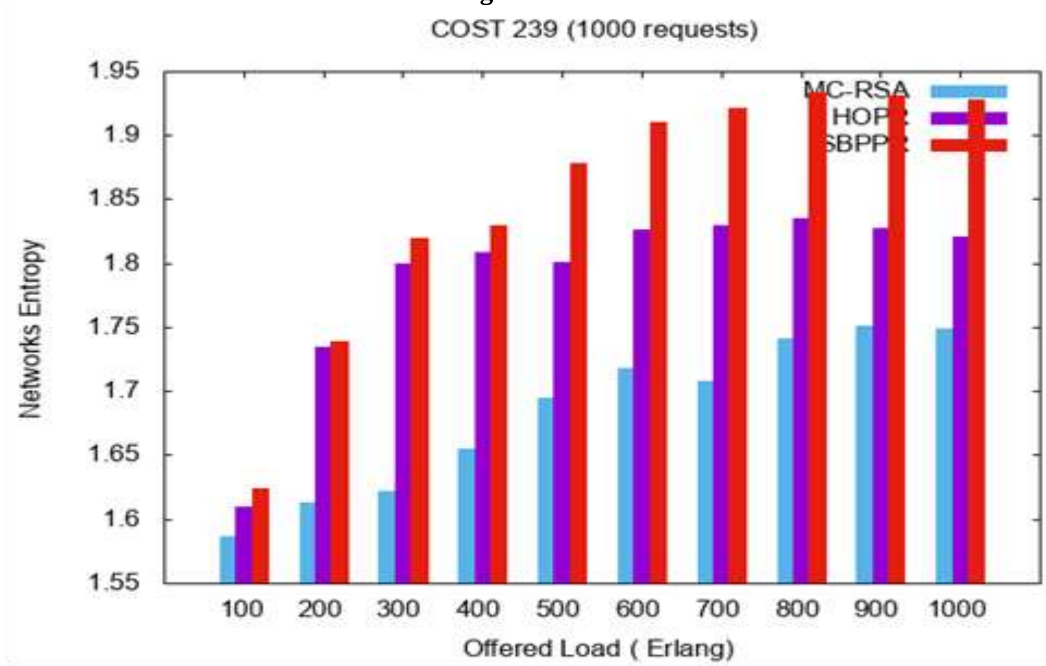
Networks Entropy 1000 requests on US BACKBONE

Image XII:-



Networks Entropy 500 requests on COST 239

Image XIII:-



Networks Entropy 1000 requests on COST 239.

Conclusion:-

In this paper, we studied dynamic routing and spectrum allocation in EONs for protected multicast connections using backup paths. Three algorithms, MC-RSA which does not use reallocation, HOP which uses reallocation without a backup path and SBBPR which uses backup paths as temporary paths for spectrum reallocation were tested. We compared the blocking probability and the fragmentation of the network links. The results show that SBPPR resource allocation has a lower blocking probability than HOPR and MC-RSA, especially when the network load increases. However this performance of SBPP is obtained at the cost of increased network fragmentation. In future work, we will investigate different strategies for applying reallocation algorithms also to find resources for backup paths.

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