Algorithm for Shared Path for Protection of Space Division Multiplexing Elastic Optical Networks

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***Abstract*—Although shared path protection has been employed for protecting traffic flows against network failures, to our knowledge, it has not been considered for path protection in elastic optical networks with space division multiplexing (SDM). In this paper, we propose an algorithm to dynamically generate primary and backup paths using a shared backup scheme. The proposed algorithm is compared to the Failure-Independent Path Protecting for MultiCore network (FIPPMC) algorithm and to the Shared path with Spectrum and Core Assignment (SSCA) algorithm. Results indicate that 100% protection for single failures can be provided by the proposed algorithm with low overhead when compared to the other two algorithms.**

***Keywords*—Survivability, Multi-core Fiber, Elastic Optical Network with Space Division Multiplexing.**

I. Introduction

The development of multi-core fiber technology as well as the development of flexibile spectrum allocation techniques in elastic optical networks (EONs) have led to the consideration of spacial division multiplexing (SDM) in EON with spatial fibers. Elastic optical networks with SDM promises to provide higher capacity and lower cost when compared to conventional single mode fiber systems [1]. If on one hand, Space-Division Multiplexing (SDM) technology allows the increase of network capacity, on the other hand, MCF produces physical impairments that reduces the spectrum usability.

The routing and spectrum allocation (RSA) problem is a fundamental problem in EON network design. RSA algorithms assign continuous and contiguous slots on all links of the selected route. The inclusion of space as a multiplexing degree of freedom adds another dimension to the RSA problem which becomes the routing, spectrum and core allocation (RSCA) problem [2].

Moreover, survivability is of paramount importance in optical transport networks that carry huge amounts of traffic. As the carried traffic increases, the need for adoption of efficient protection schemes also increases. Although there are numerous algorithms for spectrum allocation in EON networks [2]–[6], there are not so many for protection of SDM EON networks.

Shared-backup path protection (SBPP) is a protection techniques which has been extensively investigated in the past years due to the efficient sharing of spare capacity as well as flexibility in service provisioning. SBPP employs a 1:N protection scheme in which backup paths can use the same spectrum (slots), provided that their corresponding working paths are link-disjoint.

This paper introduces an algorithm called Shared Backup Path Protection for MultiCore network (SBPPMC) for providing shared protection in SDM-EONs. The SBPPMC algorithm uses backup paths interleaved with primary paths, in order to generate less crosstalk per slot. It employs a Routing and Spectrum Assignment algorithm based on a multigraph representation of the spectrum. Results show that the proposed algorithm promotes protection effectively without significantly compromising blocking.

The rest of the paper is structured as follow. Section II reviews related work. Section III introduces the proposed algorithm. Section IV evaluates the performance of the proposed algorithm and Section V concludes the paper.

II. Related Work

Shared path protection for optical networks has been extensively studied. However no previous work considered shared path protection in elastic SDM optical networks.

In [1], it is proposed an SDM multi-dimensional switching network that provides flexibility of bandwidth allocation, conventional single core and new multi-core fibres. It employs programmable Architecture on Demand (AoD) optical nodes as well as different networking functionality. Khodashenas *et.al.* [7] investigates offline RSA in a survivable EON scenario with shared backup path protection (SBPP). They formulate the RSA/SBPP as an Integer Linear Programming (ILP) problem. The implementation of FIPP-p-cycles in EONs was studied in [8]. In [9] is presentd a new algorithms to provide path protection using p-cycle path, traffic grooming and overlap spectrum in elastic optical networks. The authors in [10] evaluated the advantages of using the extra dimension introduced by space-division multiplexing (SDM) for dynamic bandwidth-allocation purposes in a flexible optical network. Hirota *et.al.* [3] divides the RSCA problem into the routing and SCA problems, and introduces a K-shortest path based pre-computation method as the routing solution. They proposed SCA methods with crosstalk awareness. In [6], EON is extended to include elasticity in all three domains: time, frequency, and space. They investigated algorithms for routing, spectrum, spatial mode, and modulation format assignment. In [2], a routing, spectrum and core allocation (RSCA) problem for flexgrid optical networks is proposed for network planning problem using integer linear programming (ILP) formulation as well a heuristic. In [11], it is proposed a scheme based on FIPP-p-cycle for protection in elastic SDM optical networks. In [11], is introduced a novel algorithm to provide Failure-independent path protecting p-cycle with minimum interference for path protection in elastic optical networks using space division multiplexing. However shared path protection is not considered.

III. The Algorithm

Solutions for the Routing, Spectrum and Core Assignment (RSCA) problem in elastic optical networks are needed to efficiently accommodate diverse traffic demands. In an RSCA formulation, routes can switch cores in different links. However, the inter-core crosstalk associated with MCF should be considered. Moreover, the problem formulation needs to consider the spectrum continuity constraint that imposes the allocation of the same spectrum in each fiber along the route of a lightpath, as well as the spectrum contiguity constraint that imposes that slots must be contiguously allocated in the spectrum.

The proposed algorithm models the spectrum availability in the network as labeled multigraph (Figure 1). A multigraph is a graph which can have multiple edges (also called "parallel edges"), that is, edges that have the same end vertice. In this auxiliary graph, vertices represent OXCs and edges the set of same slots (different cores) in the link connecting the OXCs. All the vertices are connected by N edges which is the number of slots in the spectrum of each network link, and each edge represents the availability of at least one slot. Labels on an edge represent the availability of a set of slots. An ∞ value means that all slots are already allocated whereas the value 1 means that at least one slot is available for allocation. These values were defined to facilitate the employment of traditional shortest path algorithms.

A. Notation

The following notation will be used in the paper:

s: source node; d: destination node;

b: bandwidth demand in slots, $b = 1 \ldots N$;

$r(s, d, b)$: request from the node s to the node d with bandwidth demand b in slots;

N: number of slots set between two nodes;

$G = (V, E, W)$: labeled multigraph composed by a set of nodes V, a set of edges E and a set of edge weight W, $|E| = N \cdot |V|$. The edges connecting two vertices of G represent the N slots in the link connecting two network nodes;

$E = \{e_{u,v,n}\}$: set of n edges;

$e_{u,v,n}$:the n^{th} edges connecting u and v;

$e_{u,v,n} = \{e'_{u,v,n,j}\}$ where j is a core chosen to be used.

$w(e_{u,v,n})$: weight of the edge $e_{u,v,n}$; $w(e_{u,v,n}) = 1$ if the n^{th} slot in the link connecting OXC u and v is free and $w(e_{u,v,n}) = \infty$ if the slot is already allocated;

$W = \{w(e_{u,v,n})\}$:set of edge weights

$\widetilde{G}_{n,b} = (\widetilde{V}, \widetilde{E}, \widetilde{W})$: the n^{th} labeled graph such that $\widetilde{E}$ is the set of edges connecting $\{\widetilde{u}, \widetilde{v}\} \in \widetilde{V}$ and $\widetilde{W}$ is the set of costs associated to $\widetilde{E}$. The edges in $\widetilde{E}$ correspond to the mapping of b edges in G starting at the $n^{th} edge$;

$\widetilde{V} = V$: set of nodes;

$\widetilde{e}_{u,v} \in \widetilde{E}$: edge connecting $\widetilde{u}$ and $\widetilde{v}$; $\widetilde{e}_{\widetilde{u},\widetilde{v}} = \{e_{u,v,n}\} \in E$ is a chain such that $e_{u,v,n}$ is the least ordered edge, $e_{u,v,n+b}$ is the greatest ordered edge and $|\widetilde{e}_{u,v}| = b$;

$\widetilde{w}_n(\widetilde{e}_{\widetilde{u},\widetilde{v}})$: weight of the edge $\widetilde{e}_{\widetilde{u},\widetilde{v}}$;

$\widetilde{W}_n = \{\widetilde{w}_n(\widetilde{e}_{\widetilde{u},\widetilde{v}})\}$: set of edge weights;

P_n: chain of $\widetilde{G}_n$ such that the source node s is the least ordered node and d is the greatest ordered node;

$W(\widetilde{P}_n)$: $\sum_{\widetilde{e}_{\widetilde{u},\widetilde{v}} \in \{\widetilde{P}_n\}} \widetilde{e}_{\widetilde{u},\widetilde{v}}$: the weight of the path $\widetilde{P}_n$ (the sum of the weights of all the edges in the chain;

$W_{P_{s,d}}$ = weight of the shortest path between s and d;

$\widetilde{t}_{u,v,b}$: backup path containing vertices u and v and edges corresponding to the mapping of b edges of the multigraph G;

$\widetilde{T}_{u,v,b} = \widetilde{t}_{u,v,b}$: set of all backup path containing vertices u and v and edges corresponding to the mapping of b edges of the multigraph G;

$\widetilde{T}$: set of all established backup path and active;

T_n: chain of $\widetilde{G}_n$ such that the source node s is the least ordered node and d is the greatest ordered node;

$W(\widetilde{T}_n)$: $\sum_{\widetilde{e}_{\widetilde{u},\widetilde{v}} \in \{\widetilde{T}_n\}} \widetilde{e}_{\widetilde{u},\widetilde{v}}$: the weight of the backup path $\widetilde{T}_n$ (the sum of the weights of all the edges in the chain);

$W_{T_{s,d}}$ = weight of the backup path will protect the path between s and d;

B. SBPPMC Algorithm

The algorithm introduced in this subsection, called SBPPMC (Shared Backup Path Protection for MultiCore network), decides on the establishment of lightpaths in protected networks. A lightpath is established if and only if it can be protected by a shared path.

Algorithm 1 SBPPMC

1: $\forall n = 1 ... N{-}b$
2: $\quad (W(P_n), P_n) = ShortestPath(\widetilde{G}_{n,b}, r(s,d,b))$
3: $W_{P_{s,d}} = W(P_n) |\ \forall i\ W(P_n) \leq W(P_i)$
4: **if** $W_{P_{s,d}} = \infty$ **then**
5: $\quad$ *block* $r(s,d,b)$
6: **else**
7: $\quad$ **if** $T_n \neq \emptyset \quad \forall\, T_n \in \widetilde{T}$ **then**
8: $\qquad$ establish $r(s,d,b)$ as P_n and T_n
9: $\qquad W(e'_{u,v,i}) = \infty \quad \forall \{u,v\} \in \widetilde{P}_i \quad n = n ... i{+}b-1$
10: $\quad$ **else**
11: $\qquad \forall n = 1 ... N{-}b$
12: $\qquad\quad (W(T_n), T_n) = ShortestPath(\widetilde{G}_{n,b}, r(s,d,b))$
13: $\qquad W_{T_{s,d}} = W(T_n) |\ \forall i\ W(T_n) \leq W(T_i)$
14: $\qquad$ **if** $W_{T_{s,d}} = \infty$ **then**
15: $\qquad\quad$ *block* $r(s,d,b)$
16: $\qquad$ **else**
17: $\qquad\quad$ establish $r(s,d,b)$ as $\widetilde{P}_n$ and $\widetilde{T}_n$
18: $\qquad\quad W(e'_{u,v,i}) = \infty \quad \forall \{u,v\} \in \widetilde{P}_i \quad n = n ... i{+}b-1$
19: $\qquad\quad W(e'_{u,v,i}) = \infty \quad \forall \{u,v\} \in \widetilde{T}_i \quad n = n ... i{+}b-1$
20: $\qquad$ **end if**
21: $\quad$ **end if**
22: **end if**

In this algorithm, Line 1 establishes all the set of edges that will be mapped onto $\widetilde{G}_{n,b}$ edges. Line 2 solves a shortest

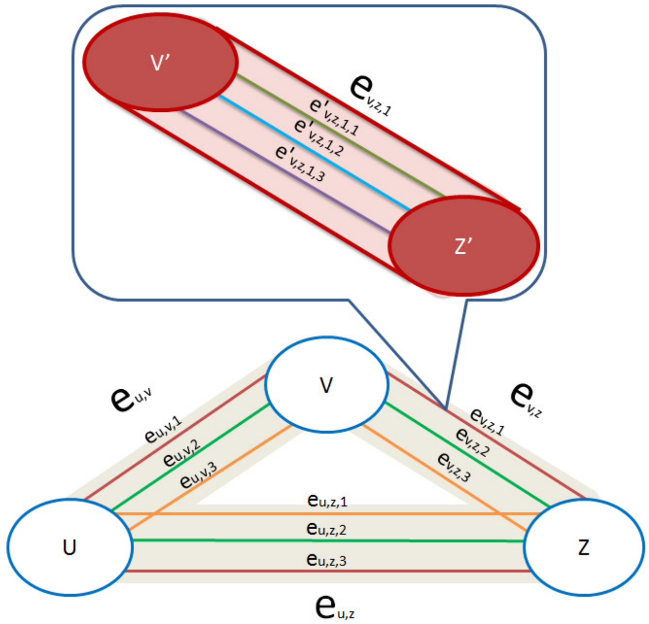
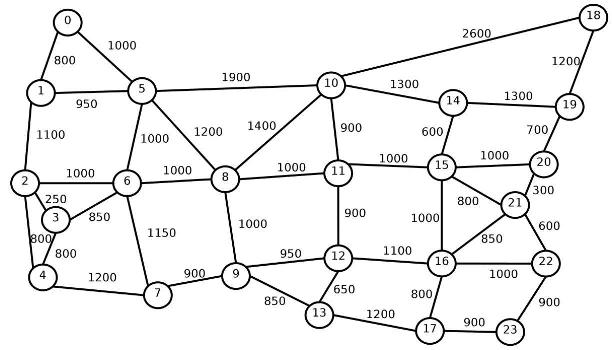
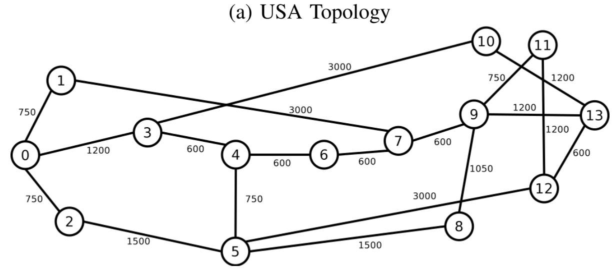


Figure 1: Multigraph



(a) USA Topology



(b) NSF Topology

Figure 2: Topologies

path algorithm for the graph $\widetilde{G}_{n,b}$ and provides the path and its weight. If the weight of the shortest path is ∞, it was not possible to find a path under the contiguity constraint for the demand b with allocation starting with the n^{th} slot. Line 3 selects the path among the $N - b + 1$ shortest paths that has the lowest weight value. In case the weight of all shortest path is ∞ (Line 4), there is no path in the network that satisfies the request of b slots under the contiguity constraint. Therefore, the request has to be blocked (Line 5). If there is no path available (Line 4) then the request is blocked (Line 5). Otherwise, a path to protect the lightpath to be established is searched (Line 7). In case there exists a path, the lightpath is established (Line 8) and the corresponding edges in the multigraph G have their weight changed to ∞ (Line 9) meaning that the slots were allocated to the newly established lightpath. Otherwise, a path to protect the lightpath to be established should be created (Lines 11 and 12). In case no path can be created to protect the lightpath then the request is blocked (Line 15). Otherwise, the primary path as well as the backup path (Line 17) are established to satisfy the request and the corresponding edges in the multigraph G have their weight changed to ∞ (Lines 18 and 19) meaning that the slots were allocated to the newly established lightpath.

IV. Performance Evaluation

To assess the performance of SBPPMC algorithm in multi-core networks, simulation experiments were employed using 7 cores. The FlexGridSim [12] simulator was employed. In each simulation, 100,000 requests were generated and simulations for all the algorithms used the same set of seeds. Confidence intervals were derived using the independent replication method with 95% confidence level. The topology used in the simulations were the NSF (Figure 2b), and the USA (Figure 2a) topologies. The NSF topology has 16 nodes and 25 links whereas the USA topology has 24 nodes and 43 links (Figure 2).

The spectrum was divided in 240 slots of 12,5 GHz. In the figures, the curves labeled "FIPPMC" show the results for networks using the algorithm FIPPMC [11], the curves labeled "SSCA" show the results for networks using the algorithm based in the methods proposed in [3], and the curves labeled "SBPPMC" display results for networks using the proposed SBPPMC algorithm. The FIPPMC algorithm decides on the establishment of lightpaths in an FIPP *p*-cycle protected network. In the SSCA algorithm, the primary path is treated independently, i.e., the routing problem and the SCA problem. This approach employs pre-computed multiple routes. The backup path is created in the same way. However, the backup path uses a 1:N scheme.

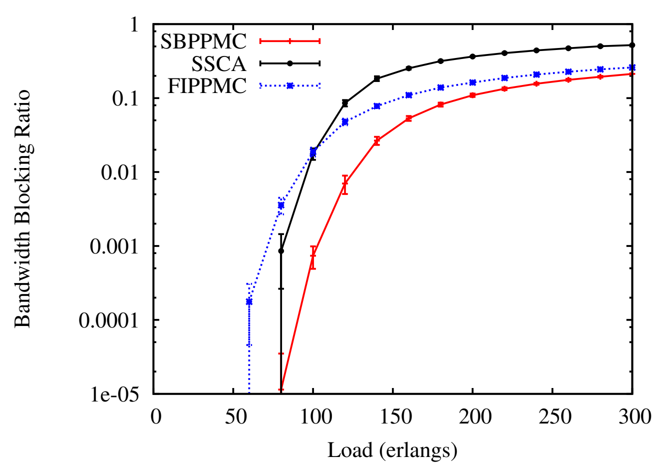


Figure 3: Bandwidth blocking ratio for the USA topology

Figure 3 shows the bandwidth blocking ratio (BBR) as a function of the load for the USA topology. While FIPPMC starts blocking requests under loads of 60 erlangs, SBPPMC and SSCA start blocking only under loads of 80 erlangs. Under loads of 80 erlangs, the difference between the BBR produced by the SBPPMC algorithm and that given by the SSCA and FIPPMC algorithm is two order of magnitude. Under high loads of 200 erlangs the difference between the BBR produced by the SBPPMC algorithm and that given by the SSCA algorithm is almost one order of magnitude and 10% when compared to that produced by FIPPMC. Such BBR values produced by SBPPMC evinces the benefit of choosing jointly the route and the core to provide protection when compared to choosing in different steps as in the SSCA algorithm. These results show that the SBPPMC algorithm produces acceptable blocking for multi core fibers with SDM.

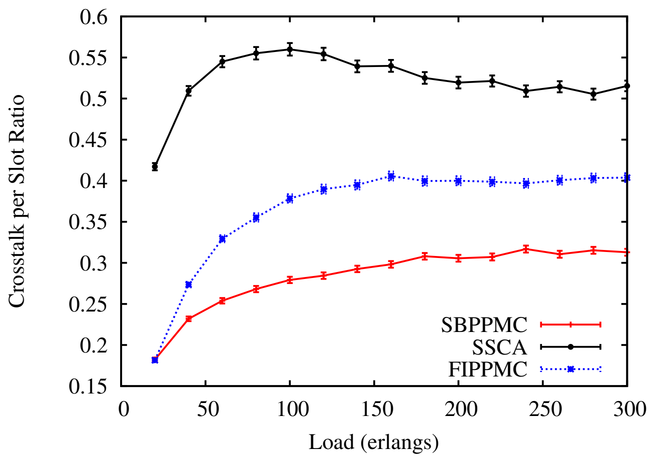


Figure 4: Crosstalk per slot ratio for the USA topology

The use of seven cores generates intercore crosstalk. Figure 4 shows the "Crosstalk per Slot" (CpS) as a function of the load for the USA topology. The crosstalk value for each spectrum slot is defined as the ratio of actual crosstalk index to the maximum value of crosstalk index. The crosstalk ratio is defined by the average value among all spectrum slots [5]. The CpS is not considered when the slot is reserved but not used. The generated CpS for the SBPPMC algorithm starts at a 0.17 value and increases until 0.32. The same happens with the generated CpS for the FIPPMC algorithm starting at a 0.17 value and increasing until 0.41. The SSCA algorithm has higher CpS than the other two algorithms. Besides the SBPPMC algorithm producing low blocking and high utilization, it also produces low CpS. Using the SBPPMC algorithm, less crosstalk is produced since connection are more uniformly distributed. The generated CpS for the SSCA algorithm remains between 0.50 and 0.53 under heavy loads. Note that the interleaved use of cores for primary and backup paths decreases the CpS generated.

Figure 5 displays the Jain Fairness Index (JFI) of the BBR for different source destination pairs. The SSCA algorithm produces high Jain index values due to high blocking which affects uniformly all source destination pairs. The SBPPMC algorithm produces low Jain Index of fairness since several source destination pairs do not suffer blocking, and therefore there is greater disparity between BBR values. The FIPPMC algorithm produces unfair distribution of blocking among

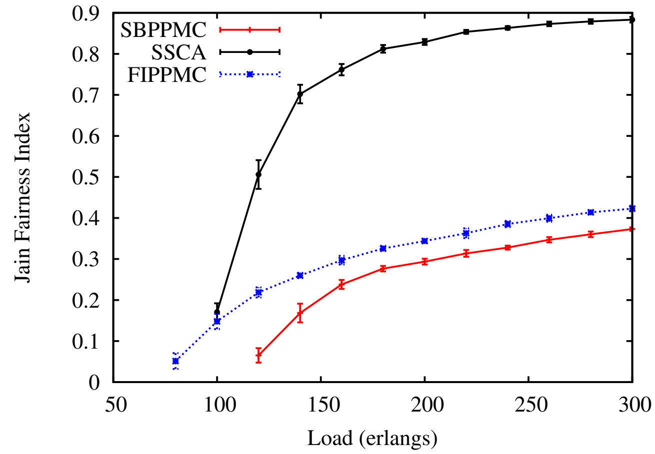


Figure 5: Jain fairness index for the USA topology

source destination pairs than does the SBPPMC algorithm. This is due to a higher number of hops to establish primary and backup paths used by FIPP algorithm.

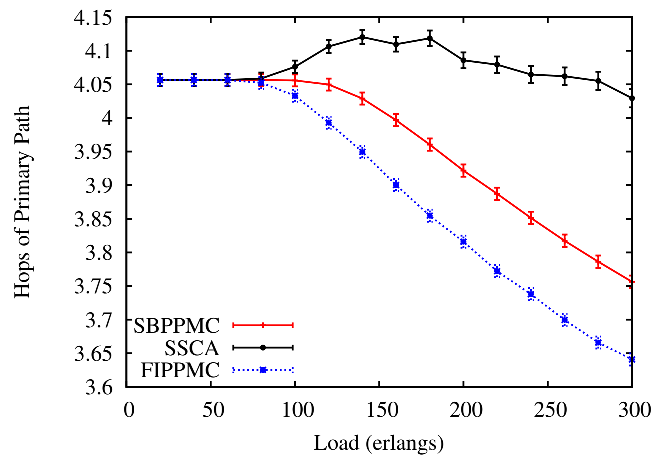


Figure 6: Average number of hops allocated per primary path for the USA topology

Figures 6 shows the average number of hops of primary paths established for the USA topology. The higher the load, the lower is the average number of hops allocated per primary path. Until loads of 80 erlangs, the three algorithms demand similar number of hops per primary path. Under higher loads, the SSCA has higher average number of hops allocated per primary path.

Figures 7 shows the average number of hops of backup paths established for the USA topology. The SSCA and SBPPMC algorithms produce an almost constant number of hops allocated per backup path regardless the network load. The number of primary backup paths allocated by the FIPPMC algorithm is always higher than those demanded by the others algorithms. This is due to the cost of the creation of p-cycle. Until 100 erlangs loads, the number of primary backup paths allocated by the SSCA and the SBPPMC algorithms are similar.

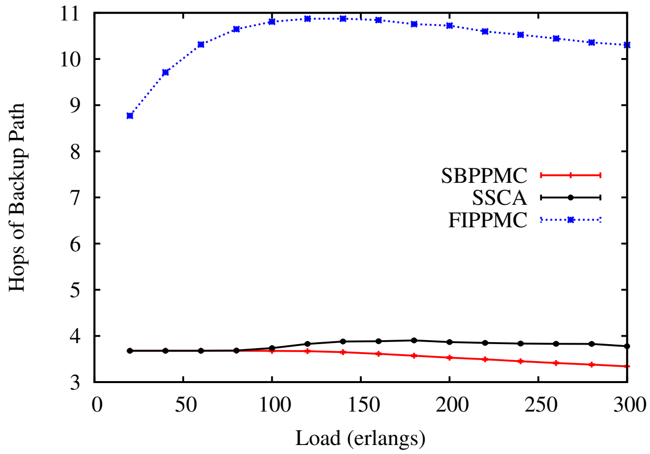


Figure 7: Average number of hops allocated per backup path for the USA topology

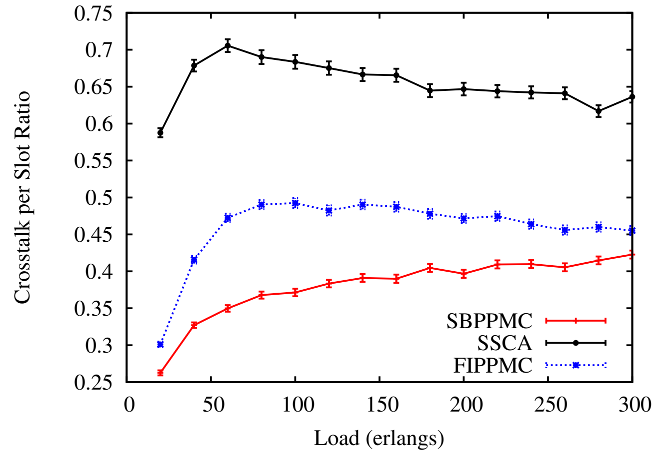


Figure 9: Crosstalk per slot ratio for the NSF topology

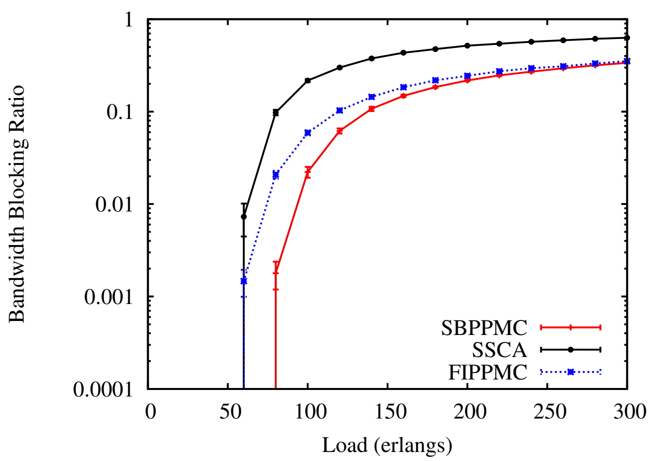


Figure 8: Bandwidth blocking ratio for the NSF topology

Figure 8 shows the bandwidth blocking ratio (BBR) as a function of the load for the NSF topology. While FIPPMC and SSCA start blocking requests under load of 60 erlangs, SBPPMC starts blocking only under loads of 80 erlangs. Under loads of 80 erlangs, the difference between the BBR produced by the SSCA algorithm and that given by the FIPPMC algorithm is almost one order and two order of magnitude higher than those given by SBPPMC. Under loads of 200 erlangs, the difference between the BBR produced by the SBPPMC algorithm and that given by the SSCA algorithm is almost one order of magnitude. Under loads of 200 erlangs, the difference between the BBR produced by the FIPPMC algorithm and that given by the SBPPMC algorithm is around 1%. The low node degree in this topology leads to the creation of bottlenecks as well as a rapid increase in blocking when compared to the blocking for the USA topology.

Figure 9 shows the “Crosstalk per Slot” (CpS) as a function of the load for the NSF topology. The CpS produced in the NSF topology is higher than that produced in the USA topology. The generated CpS for the SBPPMC algorithm start at a 0.26 value and increases until 0.42. The generated CpS for the FIPPMC algorithm start at 0.30 value and increases until 0.50 with the load increase. The generated CpS for the SSCA algorithm start at 0.58 and decreases with the load increase until 0.70.

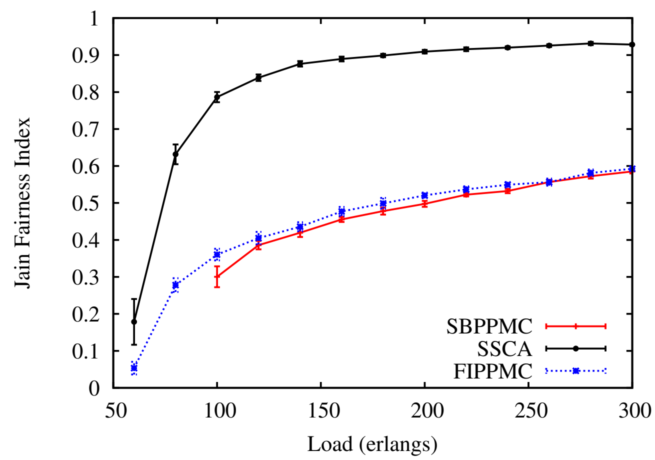


Figure 10: Jain fairness index for the NSF topology

Figure 10 displays the Jain Fairness Index (JFI) of the BBR for different source destination pairs for the NSF topology. The SSCA algorithm has high Jain index values, when compared with the other algorithms. The FIPPMC algorithm produces low Jain index values due to low blocking which affects uniformly all source destination pairs. However, SBPPMC provides lower JFI values than does FIPPMC.

Figures 11 shows the average number of hops of the primary paths established for the NSF topology. Until loads of 60 erlangs, the number of hops allocated per primary path by the algorithms are similar. Under loads higher than 60 erlangs, the SSCA demands an average number of hops per primary path higher than do the others algorithms. Under high loads, the FIPPMC algorithm demands lower average number of hops per primary path than do the other two algorithms.

Figures 12 shows the average number of hops of backup

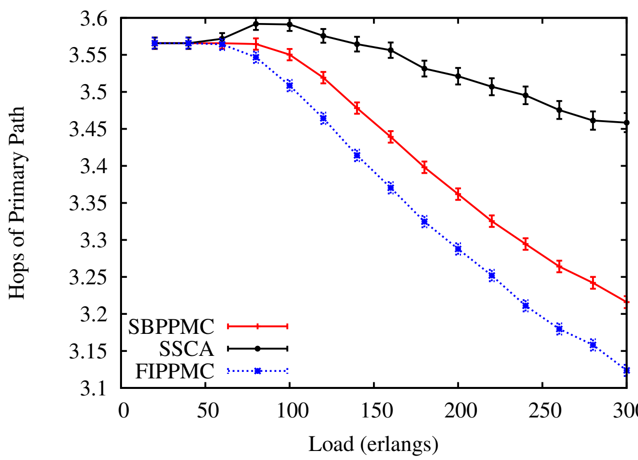


Figure 11: Average number of hops allocated per primary path for the NSF topology

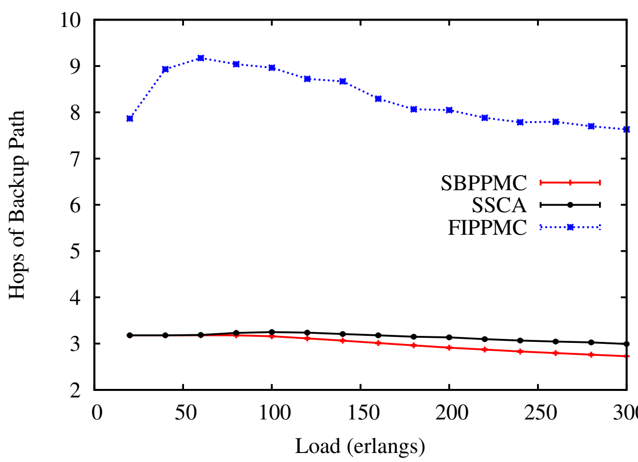


Figure 12: Average number of hops allocated per backup path for the NSF topology

paths established for the NSF topology. As for the USA, the algorithms demands an almost constant number of hops allocated per backup path regardless the network load. The number of primary backup paths allocated by the FIPPMC algorithm is always higher than the allocated by the other algorithms. It happens due to the cost of creation of p-cycles. The number of primary backup paths allocated by the SSCA and SBPPMC algorithms is quite similar.

V. Conclusion

Protection is a fundamental problem in optical networks, especially in SDM elastic optical networks in which traffic is concentrated on few links, which increases the damage caused by a single failure. This paper introduced an algorithm to support the establishment of lightpaths in SDM elastic optical networks protected by shared path protecting. The SBPPMC algorithm provides 100% protection for single failures. Results indicated that the overhead demanded by the SBPPMC algorithm is quite acceptable for networks with high node connectivities (USA) but it is not so attractive to networks with low node connectivity (NSF), when compared with the FIPPMC algorithm.

Acknowledgments

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