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Alternative Routing and Zone-Based Spectrum Assignment Algorithm for Flexgrid Optical Networks

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Abstract

In optical flexgrid networks, the optical spectrum can be allocated at a much finer granularity that it can be allocated in fixed-grid WDM networks, and connections can use a variable number of slots. However, the dynamic establishment and tear down of lightpaths demanding variable spectrum widths yields to the fragmentation of the spectrum with increase in blocking of connections; mainly connections demanding large spectrum widths. This papers proposes a novel algorithm that introduces a zone-based assignment policy together with an alternative path routing mechanism based on the maximum capacity available. Results derived via simulation using different topologies and considering connections requests from 40Gbps to 1000Gbps, show that the proposed algorithm leads to blocking ratio consistently lower than those given by traditional approaches. Furthermore, it reduces the blocking ratio of high rates connections, in some cases, in more than six times.

1 Introduction

The Internet architecture does not impose constraints in the application layer which allows the fast emergence of all kind of applications with heterogeneous bandwidth requirements. Applications such as e-mail and voice over IP demand low bandwidth, but other ones such as IPTV, video on demand and grid applications can demand a huge amount of bandwidth; in some cases, in the order of Gbits per second[1].

The evolution of optical networks has played an important role to support the growing demand for bandwidth. In this context, the wavelength division multiplexing (WDM) technology brought great capacity to the network link layer by allowing multiplexing of several wavelengths (optical channels) in a single fiber link. In WDM links the optical spectrum is divided into frequency slots of fixed width 100GHz or 50GHz, allowing up to 40 and 80 optical channels, respectively. Despite this rigid frequency grid, the optical transmission systems have evolved and the use of advanced modulation techniques, allowed rates higher than 100Gbps per optical channel in WDM networks. Nevertheless, the rigid

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frequency width of 100GHz and 50GHz becomes a barrier to optical transmissions at higher rates, e.g. 400Gpbs and 1000Gbps which demand frequency slots larger than 100GHz. Furthermore, optical transmissions at low rates can be done using less than 50GHz which yields to inefficient use from the optical spectrum of WDM links.

The necessity to support both high and low rates in an spectrum-efficient way motivated the adoption of less rigid frequency slots division to accommodate requirements with heterogeneous spectrum. In this context, the flexgrid optical networks have gained great momentum and have attracted attention from industry and academia due to the technology maturity that enables their development and deployment. In optical flexgrid link, the spectrum is also divided into fixed slots, but in finer granularity, e.g. 12.5GHz or even 6.25GHz; and optical channels can be allocated into a variable number of slots according to the requested bit rate and modulation technique applied.

Similar to the routing and wavelength assignment problem (RWA) in fixed-grid WDM networks, solutions for the routing and spectrum assignment problem (RSA) in optical flexgrid networks are needed to efficiently accommodate the optical channels. Besides the spectrum continuity constraint that imposes the assignment of the same spectrum slots for all links of the optical channel, as is the wavelength continuity constraint for RWA problem, the RSA problem also needs to consider the spectrum contiguous constraint that imposes the assignment of contiguous slots for all links of the optical channel.

In optical flexgrid networks, the mix of connections requiring a variable number of slots leads the optical spectrum to the fragmentation of the available spectrum into small noncontinuous slot chunks, becoming difficult to allocate new connections, mainly, high rate connections that demand many contiguous slots. The fragmentation problem is even more striking in dynamic scenarios, in which connections are frequently established and teared-down. Thus, it is of extreme importance that routing and spectrum assignment should be carried out in a way to minimize the fragmentation impact.

In this context, this paper proposes an innovative way to handle the RSA problem, whose the major idea is to consider the optical spectrum as divided into small spectrum ranges rather than a single large spectrum range; such small spectrum ranges are called zones. Moreover, attempts are made to allocate connections in preferential zones according to their types. Applying a zone-based assignment policy together with an alternative routing path policy based on the maximum capacity available, we propose a novel and powerful algorithm for the dynamic RSA problem. Results derived via simulation using different topologies and considering connections requests from 40Gbps to 1000Gbps, show that the proposed algorithm leads to blocking ratio consistently lower than those given by traditional approaches. Furthermore, it reduces the blocking ratio of high rate connections, in some cases, in more than six times.

This paper is organized as follow. The next section describes related work. Section 3 introduces the dynamic RSA problem and the idea of a zone-based assignment policy. Section 4 describes, in details, the proposed algorithm. Section 5 presents performance results. Section 6 concludes the paper.

2 Related Work

Solutions to the RSA problem have been proposed for both static and dynamic scenarios. For the first, the traffic matrix is known in advance and the objective of the problem is to minimize the spectrum used to serve the traffic matrix. For the second, the traffic matrix is unknown and connections arrive and departure along the time and the objective is to minimize the blocking ratio.

Several works in literature propose integer linear formulations for the static (offline) RSA problem, [2, 3, 4]. However, this kind of approach suffers from the huge computational complexity; being impracticable to obtain optimal results for large instances in an acceptable time. In [2], the authors decouple the original formulation into two sub-problems: (i) a demanding routing sub-problem and (ii) a spectrum assignment sub-problem; and solve them separately. In [3], the authors propose a formulation and a heuristic approach to obtain near optimal solutions. In [4], the authors propose a formulation based on pre-computed set of spectrum contiguous frequency slots that remove the complex spectrum contiguity variables and constraints from the formulation, making it solvable.

For the dynamic (online) RSA problem, two main heuristic approaches are applied in the literature. The first one is a two-step approach, which decouples the problem into two sub-problems: (i) the routing sub-problem and (ii) the spectrum assignment sub-problem; and solves them separately. The second is a one-step approach that jointly solves the routing and spectrum assignment sub-problems.

Solutions for the two-step approach are, basically, classified in fixed shortest-path routing [5, 6, 7] and alternative path routing [8, 9, 10]. The first class of algorithms calculates a shortest path for all pairs of nodes and applies some spectrum assignment policy to the shortest path. The second class of algorithms calculates a set of potential paths among all pairs of nodes, chooses one of the paths and applies some spectrum assignment policy. For both classes of algorithms the first-fit spectrum assignment policy is most used [6, 7, 10]. Some works propose different policies such as most-used spectrum assignment policy [9] and the maximization of the common large segment policy [8].

Solutions for the one-step approach tends to produce good results, but it is usually more complex and time consuming. In [11], the authors propose two algorithms: the Modified Shortest Path (MSP), which is a modified Dijkstra algorithm that does not search for all paths, and Spectrum Constraint Path Vector Searching (SCPVS) that searches for all potential paths which produces lower blocking ratio than does the MSP.

In [12], the authors propose traffic aggregation to diminish fragmentation in optical flexgrid networks. In [13], the authors propose a mechanism for matching spectrum fragmentation and bandwidth demands. The work in [14] introduces mechanisms to avoid and ameliorate fragmentation. In [15], an algorithm to reallocate the connections according to existing fragmentation and the pattern of slot use is introduced.

The present work introduces a novel alternative routing and spectrum assignment algorithm that differs from the existing ones by the introduction of the zone concept which aims to segment the optical spectrum in non-overlapping zones in order apply a two-step routing and spectrum assignment approach following a rank of preferential zones.

3 Dynamic Routing and Spectrum Assignment

The dynamic routing and spectrum assignment problem in flexgrid optical networks can be stated as follows.

Given:

- A flexgrid optical network, represented by a graph $G(N, E)$, where N is the set of optical nodes and E is the set of fiber links connecting two nodes in N.
- An ordered set S of frequencies in each fiber link $e \in E$; $S = \{s_1, s_2 \dots s_n\}$.
- Online arriving connection requests $r = (i, j, c)$, where $i, j \in N$ are the source and destination nodes and $c \in C$ is the amount of continuous and contiguous slots required.

Output: For each online connection request, the route over the flexgrid optical network and the spectrum assignment.

Objective: Minimize the amount of rejected slots.

It has been proved that the dynamic RSA problem is NP-hard calling for heuristics one of the most appropriate approaches. The most common heuristic to solve the problem is to decouple the problem into two sub-problems: (i) the routing sub-problem and (ii) the spectrum assignment sub-problem; and solve them separately.

The proposed algorithm applies the decoupling strategy in a different way. It segments the optical spectrum into non-overlapped ranges, which we call zones, and associate each zone with connections requiring the same amount of slots. For instance, if there are three types of connection requests $(i, j, c1)$, $(i, j, c2)$ and $(i, j, c3)$, where $i, j \in N$ and $c1, c2, c3 \in C$, it will be built one preferential zone for each type of connection: $z_1 = \{s_1, s_2 \dots s_i\}$, $z2 = \{s_{i+1}, s_{i+2} \dots s_j\}$ and $z3 = \{s_{j+1}, s_{j+2} \dots s_n\}$, where $z1 \cup z2 \cup z3 = S$ and $z1 \cap z2 \cap z3 = \emptyset$.

When a connection request r arrives, the preferential zone for that connection is chosen by the proposed algorithm. Pre-computed candidate paths are ranked for the chosen zone according to a determined criteria such as number of hops or maximum available capacity. Following the path rank, the required amount of slots are allocated into the spectrum range of the preferential zone by a first-fit approach. If it's not possible to accept the connection, the procedure will be repeated for the remaining zones, but applying a last-fit approach in order to interfere less with the connections that have preference for that zone.

Fig. 1 illustrates the proposed zone-based assignment policy. The optical spectrum is split into two zones: z_1 and z_2 in order to route two types of connections. Zone z_1 is totally available while zone z_2 has some occupied slots (shaded slots). A new connection request r can be allocated in the preferential zone z_1 by a first-fit assignment mechanism or in the non-preferential zone z_2 by a last-fit assignment mechanism.

The major goals of the zone-based policy are: (i) guarantee better allocation chances to the different types of connections by mean of pre-defined zones and (ii) avoid the fragmentation of the optical spectrum due to the mix of different types of connections, which can originate unusable fragments.

Some of the advantages of the zone-based policy are illustrated in Fig. 2. It compares the proposed policy with the traditional first-fit policy. In the example, there is a network

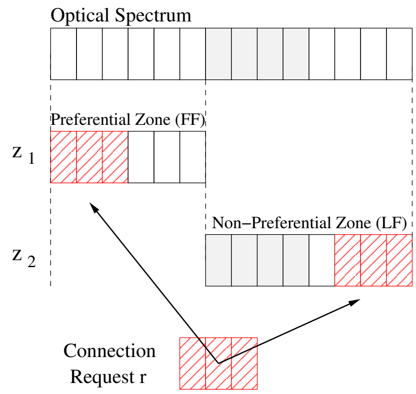

Figure 1: Example of zone-based assignment approach.

segment with four nodes (n_1, n_2, n_3, n_4) and three links (e_1, e_2, e_3) with 14 slots in the optical spectrum. Five connection requests arrived and were allocated by both policies. For the first-fit, the mix of different types of connections in the optical spectrum causes a fragmentation of slot four in links e_2 and e_3, becoming them unusable once there are only connections demanding three and four slots. Also the connection request r_5 cannot be allocated due to the unavailability of slots caused by fragmentation. For the zone-based, each type of connection is allocated in a preferential zone, avoiding the fragmentation due to the mix of different types of connections. This approach enables the acceptance of the connection request r_5. Note that the spectrum is also fragmented in the zone-based but the fragments have higher chances to be used.

More details of the the proposed algorithm are given next.

4 Alternative Routing and Zone-Based Spectrum Assignment

The following notation has been defined to describe the algorithm:

$P_{(s,d)}$ is a set of candidate paths for a pair of nodes (s, d).

Z is a set of zones.

C is a set of types of connections.

$\overline{Z}_c$ is a priority queue of zones for a connection type c.

$\overline{P}_z$ is a priority queue of paths for a zone z.

c is a connection type.

z is a zone.

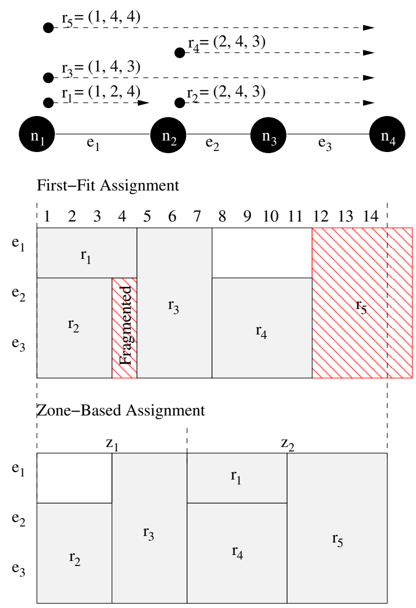

Figure 2: Example of first-fit assignment versus zone-based assignment.

r is a connection request.

p is a path.

(s, d) is a pair of source and destination nodes.

A pseudo-code of the algorithm is presented in Algorithm 1. First, an offline phase, Lines 1 to 2, computes candidate paths and divides the optical spectrum into zones. In Line 1, a k-shortest path algorithm is run to compute k paths for each pair of nodes (s, d) in the topology. These k-paths are stored in sets $P_{(s,d)}$ to be used in the online phase. In Line 2, the optical spectrum is divided into zones with one zone z for each type of connection $c \in C$. The size of each zone is given by the following rule: $c\lfloor\sum_{s\in S} 1/\sum_{c\in C} c\rfloor$, and when the sum of the size of the zones is less than the size of the optical spectrum, the difference is added to the size of the largest zone. Once computed the size of the zones, the optical spectrum is assigned to them in an increasing order of size, i.e., from the smallest zone to the largest one.

An online phase, Lines 3 to 22, is executed for every connection request $r = (s, d, c)$. In Line 4, the set of zones Z are ranked in a priority queue $\overline{Z}_c$. The pre-defined zone for the connection type c is the preferential zone and has highest priority followed by the next zones in the optical spectrum in a cyclic way. For instance, if the optical spectrum is split into zones: $z_1, z_2 \ldots z_i \ldots z_n$ and z_i is the preferential zone for the connection type c, the zone rank $\overline{Z}_c$ will be $z_i, z_{i+1} \ldots z_n, z_1, z_2 \ldots z_{i-1}$.

The algorithm tries to route and assign spectrum following the zone rank. In Line 6, a zone z is popped from the priority queue $\overline{Z}_c$. Then, in Line 7, the paths $p \in P_{(s,d)}$ are

Algorithm 1: Alternative Routing and Zone-Based Spectrum Assignment Algorithm˜

1 Compute a set of k-shortest paths $P_{(s,d)}$ in the network topology for each pair of nodes (s, d)
2 Divide the spectrum into a set of zones Z with a zone $z \in Z$ for each type of connection $c \in C$
3 **foreach** *online connection request* $r = (s, d, c)$ **do**
4 Rank the zones $z \in Z$ in a priority queue $\overline{Z}_c$ for each type of connection $c \in C$
5 **while** $\overline{Z}_c \neq \emptyset$ **do**
6 Pop zone z from priority queue $\overline{Z}_c$
7 Rank the paths $p \in P_{(s,d)}$ in a priority queue $\overline{P}_z$
8 **while** $\overline{P}_z \neq \emptyset$ **do**
9 Pop path p from priority queue $\overline{P}_z$
10 **if** $\exists c$ *continuous and contiguous slots available in zone* z *for path* p **then**
11 **if** *zone* z *is the preferential zone for* r **then**
12 Accept connection r using path p and the first $c-$slots available in zone z
13 **end**
14 **else**
15 Accept connection r using path p and the last $c-$slots available in zone z
16 **end**
17 Go to Line 3 to wait for the next connection
18 **end**
19 **end**
20 **end**
21 Reject connection r
22 **end**

ranked in a priority queue $\overline{P}_z$.

Modifying the path rank function, we created two versions of the algorithm: the K-Shortest Path and Zone-Based Assignment (KSP-ZBA) and the Maximum Capacity Path and Zone-Based Assignment (MCP-ZBA). In the first one, the paths $p \in P_{(s,d)}$ are ranked in increasing order of the number of hops of p. In the second one, the paths $p \in P_{(s,d)}$ are ranked in decreasing order of the residual capacity into zone z. The residual capacity of path p for zone z is given by the sum of the slots in zone z that are available in all hops of the path p.

Following the path rank, a path p is poped from priority queue $\overline{P}_z$ in Line 9. Then, in Line 10, it is checked if path p has c continuous and contiguous slots available in zone z. Once it is false, the next path in the path rank $\overline{P}_z$ will be tested. Otherwise, in Lines 11 to 16, the connection r will be accepted and routed using path p with the c-first available slots if z is the preferential zone for connection r or the c-last avaiable slots in zone z. After accept the connection, in Line 17, the algorithm goes back to the beginning of the online phase.

If tested all combinations of paths and zones, and a route and spectrum is not found for the requested connection, it will be rejected in Line 21, and the algorithm goes back to the beginning of the online phase.

5 Numerical Evaluation

Simulation was performed to assess the effectiveness of the two versions of the proposed algorithm: KSP-ZBA and MCP-ZBA. Results obtained by both algorithms are compared to those obtained by two RSA algorithms that does not apply the zone-based assignment policy, denoted as KSP-FFA and MCP-FFA. The only difference for the first two algorithms is that they consider the whole optical spectrum as one zone and allocate all connections, independent of its type, in this unique zone by first-fit assignment. For all algorithms, the number of k-shortest paths was set to 5.

The NSF, USA and PanEuropean topologies, respectively, with 16, 24 and 28 nodes and 25, 43 and 41 links were used. All links were defined as bidirectional with 320 slots of 12.5 GHz.

In each simulation, 10^6 connection requests are generated. These requests are uniformly distributed among all pairs of nodes and also uniformly distributed among all types of connections, which are: 40Gpbs, 100Gpbs, 400Gpbs, and 1000Gbps with requires, respectively, 3, 4, 7, and 16 slots using DP-QPSK modulation. The requests arrive according to a Poisson distribution and the holding times are sampled from a negative exponential distribution with a mean of one unit of time. Confidence intervals with 95% confidence level were derived.

The main metric used to evaluate the algorithms is the slot blocking ratio (SBR), which corresponds to the percentage of the amount of blocked slots over the total slots requested. Results for the SBR metric as a function of the network load is shown in Fig. 3, Fig. 4 and Fig. 5 for topologies NSF, USA, and PanEuropean respectively.

In NSF topology under loads lower than 140 Erlangs, the MCP-ZBA algorithm produces smaller SBR values than does the KSP-ZBA algorithm; and the MCP-FFA produces smaller SBR values than does the KSP-FFA algorithm. Note, for this load range, the strategy of choosing paths based on the maximum capacity policy outperforms strategy based on the k-shortest paths, but under loads higher than 140 Erlangs, the behavior is inverse since the maximum capacity policy tends to have longer paths and consumes more resources; consequently, it causes higher SBR values. The zone-based assignment policy outperforms the first-fit for all evaluated load range, as can be observed comparing the SBR values produced by algorithms KSP-ZBA and MCP-ZBA with the SBR values produced by algorithms KSP-FFA and MCP-FFA.

For the USA and PanEuropean toplogies, the algorithms based on zone assignment policy outperforms the algorithms based on the first-fit for all the evaluated load range, as can be seen in Fig. 4 and Fig. 5. The algorithm MCP-ZBA produces the smallest SBR values due to the effectiveness of the combination of the maximum capacity policy for choosing the path and the zone-based policy for assigning the optical spectrum. The algorithm KSP-FFA

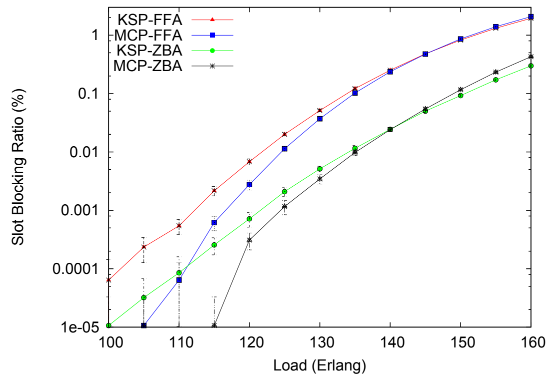

Figure 3: Slot blocking ratio for NSF topology.

produces the worst values and the algorithm MCP-FFA is outperformed by the algorithm KSP-ZBA under loads higher than 160 Erlang for the USA topology (Fig. 4) and higher than 120 Erlang in PanEuropean topology (Fig. 5).

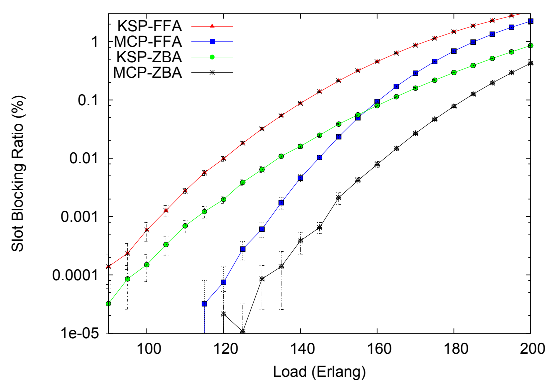

Figure 4: Slot blocking ratio for USA topology.

Fig. 6, Fig. 7 and Fig. 8 show the blocking probability for each type of connection for the topologies NSF, USA and PanEuropean under loads of 160 Erlang, 200 Erlang and 140 Erlang respectively. In all scenarios the highest blocking values, independent of the algorithm, are for connections of 1000Gbps which requires 16 slots.

The algorithms do not have problem to accept smaller connections demanding 40 Gbps and 100Gbps, which requires 3 and 4 slots respectively. The blocking probability values for connection of 400Gbps, which requires 7 slots, are very small with KSP-FFA and MCP-ZBA producing the worst values.

It is clear that one of the challenges for good RSA algorithms is to guarantee fairness between the different types of connections. Connections that demands higher amount of slots tends to be harmed due to the fragmentation of the optical spectrum. The algorithms

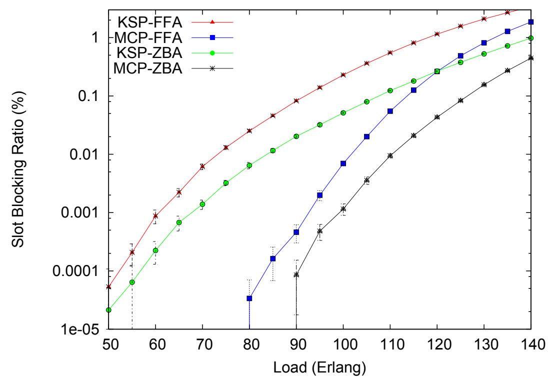

Figure 5: Slot blocking ratio for PanEuropean topology.

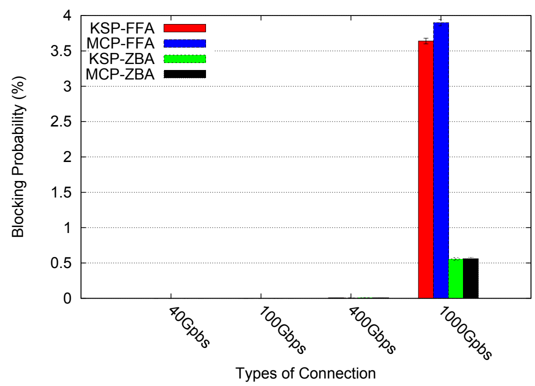

Figure 6: Blocking probability per connection type for NSF topology under load of 160 Erlang.

based on zone-based assignment policy produced significant less blocking for the highest rate connection type than do the algorithms based on the first-fit policy. This qualifies the zone-base assignment policy as a promising assignment policy for the dynamic RSA problem.

6 Conclusion

The present paper has introduced the zone-based assignment policy for the dynamic RSA problem in optical flexgrid networks. The major idea is to divide the optical spectrum into zones and allocate the connection requests in pre-defined zones in order to avoid the fragmentation of the optical spectrum due to the mix of different types of connection and to guarantee better allocation chances for all types of connections.

Our proposal of zone-based assignment policy together with an alternative path routing

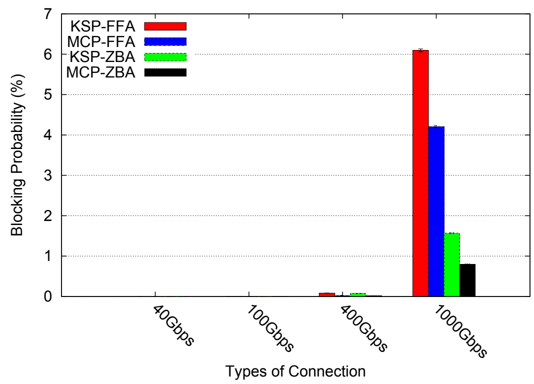

Figure 7: Blocking probability per connection type for USA topology under load of 200 Erlang.

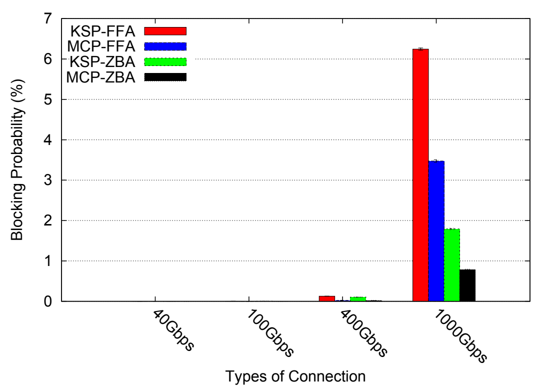

Figure 8: Blocking probability per connection type for panEuropean topology under load of 140 Erlang.

approach based on the maximum capacity policy originates a powerful algorithm for the dynamic RSA problem; producing consistently lower blocking ratio than those given by traditional approaches. Furthermore, it reduces the blocking ratio of high rates connections, in some cases, in more than six times.

Future research will investigate more deeply the zone-based assignment policy in order to analyze the impact of the size of the zones and some strategies of creating non-shared and shared zones. It is also an objective to extend the algorithm to handle modulation aspects involving bandwidth and distance constraints.

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