Evaluation of Routing Algorithms in Dynamics Optical Networks with Traffic Grooming

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***Abstract*—Three routing strategies – fixed, fixed-alternate and adaptive – are compared from the point of view of blocking probability, considering dynamic optical networks that use traffic grooming. Three different topologies are tested: mesh network with five nodes, mesh-torus network with nine nodes and the National Scientific Foundation Network. In the simulations the offered load in the network is fixed and the number of wavelengths is varied. The blocking probability for each network topology is computed and the performance of the fixed-alternate routing is shown to exceed the other strategies.**

I. Introduction

The Internet services demanded high quality of service (QoS) on the infrastructure of communications networks. This QoS is directly related to the transmission delay, the available bandwidth, blocking probability. Optical networks using wavelength division multiplexing (WDM) have achieved increasing acceptance to route the traffic on the Internet.

The networks users are connected by lightpaths. That is implemented by selecting a set of physical links between the source and destination edge nodes, and reserving a particular wavelength on each of these links [1].

A unique feature of optical WDM networks is the tight coupling between routing and wavelength selection. Thus, to establish an optical connection, one must deal with both routing (selecting a suitable path) and wavelength assignment (allocating an available wavelength for the connection). The resulting problem is referred as the routing and wavelength assignment (RWA) problem [2], and it is significantly more difficult than the routing problem. The additional complexity arises from the fact that routing and wavelength assignment are subject to the following constraints: a lightpath must use the same wavelength on all the links along its path from source to destination nodes, and all lightpaths using the same link (fiber) must be allocated distinct wavelengths. This is called wavelength continuity constraint.

The selection of route and wavelength assignment are very important problems for the control plane of WDM networks and has received attention from the research community. Several RWA algorithms have been developed for static routing, when the traffic demand does not change or changes during long time intervals. This is an interesting approach in the network design phase, when it is necessary to optimize the network capacity. However, in practice, the traffic demand is dynamic, i.e., changes randomly with time, and the application of the optimization techniques to dynamic traffic is not practical because of their prohibitively large computation time.

In this paper the performance of the combined use of three routing strategies with traffic grooming is analyzed, considering the blocking probability as a comparison metric. This evaluation is performed considering fixed offered load in the network and a variable number of wavelengths.

The approach adopted, considering a joint use of different routing approaches, with traffic grooming, is an interesting solution to control the network congestion and improve the network performance.

The remaining of the paper is organized as follows. Section II presents some important related works. Section III presents the routing strategies considered. Section IV presents the traffic grooming algorithm implemented. Section V presents the simulation environment and the analysis of results. Section VI summarizes the paper.

II. Related Works

Dynamic routing in the WDM network has been studied extensively in the literature. In Mokhtar and Azizoglu [4] an analytical model is developed for evaluating the blocking performance of various routing algorithms, including adaptive unconstrained routing which does not restricted the path selection to any pre-defined set of routes. Brunato *et. al.* [5] proposed load balancing algorithms through adaptive routing for IP-based optical networks. Bhide *et. al.* [6] and Dante [7] present new weight functions that exploit the correlation between blocking probability and the number of hops involved in connection setup to increase the performance of the network. Milliotis *et. al.* [8] address the same weight functions, but, they extend the analysis to multi-fiber optical networks. Yoo *et. al.* [9] present a new algorithm for adaptive routing based in near-maximum number of available wavelength between two nodes and evaluate its blocking performance.

The blocking performance for grooming networks with shortest-path routing has been studied in Thiagarajan and Somani [10] and Srinivasan and Somani [11], which consider the approach of traffic grooming in dynamic networks. However, comparative studies of performance for different routing

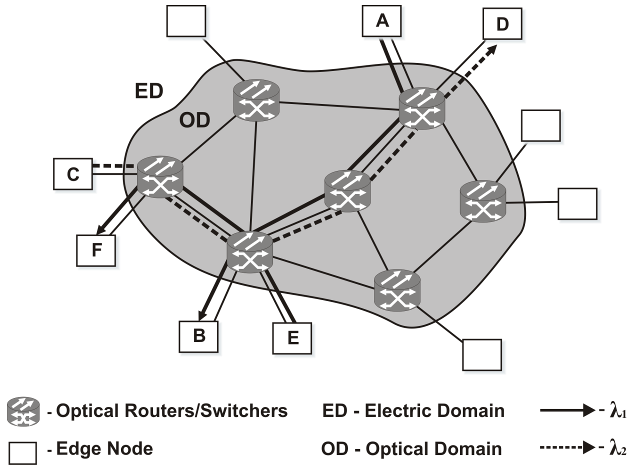

Fig. 1. Representation of an optical network.

strategies with traffic grooming in dynamic optical networks has received very little attention in the literature, although it has been studied in the context of quality-of-service routing for optical networks. This motivates the research presented in this paper.

III. Routing in Optical Networks

The selection of a lightpath is a choice of a route between a source node and a destination node, considering the best cost for a certain metric, and the wavelength assignment, typically uses heuristic algorithms. An additional complexity arises from the fact that a lightpath must use the same wavelength on all the links along its path from source to destination node, and all lightpaths that use the same link (fiber) must be allocated distinct wavelengths. This constraint is called Wavelength Continuity Constraint (WCC).

Figure 1 illustrates a wavelength-routed network in which lightpaths have been set up between pairs of access nodes on different wavelengths. Because the lightpaths between A and B and between C and D use common links, the same wavelength can not be used by them in accordance with the WCC. However, if one establishes a lightpath between E and F, as there are common links with the first lightpath established, the wavelength λ_1 may be chosen again [1], [2].

The network topology is represented as a graph $G(V, E)$, in which V denotes the set of vertices (network nodes) and E the set of edges (links). Each link $(i, j) \in E$ is associated with a weight w_{ij} which denotes the cost of using that link.

In this paper, three routing approaches are analyzed:

A. Fixed Routing

In fixed routing a single fixed route is predetermined for each source-destination pair. When a connection request arrives, the network attempts to establish a lightpath along the fixed route. If no common wavelength is available on every link in the route, the connection is blocked.

A fixed routing approach is simple to implement; however, it is very limited in terms of routing options and may lead to a high level of blocking. In order to minimize the blocking in fixed routing networks, the predetermined routes are selected to balance the load across the network links. Fixed routing schemes do not require the storage of global network state information [2]. This approach is implemented using the Dijkstra's algorithm.

B. Fixed-Alternate Routing

In fixed-alternate routing, each node in the network is required to maintain a routing table that contains an ordered list of a number of fixed routes to each destination node. For example, these routes may include the shortest-path route, the second-shortest-path route, the third-shortest-path route, etc. When a connection request arrives, the source node attempts to establish the connection on each of the routes from the routing table in a sequence, until a route with a valid wavelength assignment is found. If no available route is found from the list of alternate routes, then the connection request is blocked and lost. This approach is implemented using Yen's algorithm, that selects the k shortest paths between a node pair [2], [13].

C. Adaptive Routing

Adaptive routing increases the likelihood of establishing a connection by taking into account network state information. When global information is available routing decisions may be made with full information as to which wavelengths are available on each link. In order to find an optimal route, a cost may be assigned to each link based on wavelength availability, and a least-cost routing algorithm may be executed. The network state is determined by the set of all connections that are currently in progress [2], [4].

In this routing approach, when a connection is established, the cost of the links composing the selected route is increased, based in a cost function. When those links are released, the cost function decreases.

In this article, the link cost is altered using the number of used wavelengths as a metric. To describe the considered cost function, let define $P = \{e_1, e_2, \ldots, e_L\}$, $\forall\, e_i \in E$, a path composed by L links, with $i = 1, 2, 3, \ldots, M$, in which M is the maximum number of active links of the network. The total cost of the path P is the sum of the link costs,

$$C_{T,P} = \sum_{i=1}^{L} C_{e_j,P}, \tag{1}$$

in which $C_{T,P}$ represent the total cost of the path P and $C_{e_i,P}$ is an individual cost for the link $e_i \in P$.

The cost function adds one to the cost value when a connection is established and subtracts one from the cost value when a connection is finished in the lightpath. Therefore, the cost function is

$$C_{ij}^{n} = \begin{cases} C_{ij}^{n-1} + 1, & \text{if a new connection is established,} \\ C_{ij}^{n-1} - 1, & \text{if an active connection is finished.} \end{cases} \tag{2}$$

The initial condition of problem is the initial cost of all links, $C_{ij}^0 = 1, \forall (i,j) \in E$. The setup of a connection increases the cost value in each link of the connection and the liberation of a connection decreases this cost. This situation occurs up to the maximum cost value $C_{ij} = \infty$. This value represents the occupation of all wavelengths on the link. Therefore, if a connection was established in a route, the cost of links on this route will be increased for the next requisition, avoiding the occupation of these links. The result of this operation is a uniform distribution of the load in the network [13].

IV. TRAFFIC GROOMING

The minimum granularity of a connection in a wavelength-routed network is the capacity of a wavelength. The transmission rate on a wavelength increases with advances in the transmission technology. However, the requirement of end-users such as Internet service providers (ISPs), universities, and industries are still much lower than the capacity of one wavelength. The bandwidth requirement will increase in the near future, and doubling the current bandwidth would be more than sufficient to handle the projected demand. The current transmission rate on a wavelength is 10 Gbit/s (OC-192). At the time of writing, 40 Gbit/s (OC-768) technology is commercially available, however it is not widely deployed.

The large gap between the user requirement and the capacity of a wavelength has forced the need for wavelength sharing mechanisms that would allow more then one user to share the wavelength channel capacity. Wavelength sharing, similar to sharing a fiber using multiple wavelengths, can be done in several ways. One approach to share a wavelength is to divide its bandwidth into frames containing a certain number of time slots. A time slot on successive frames would then form a channel. Other approaches such as phase modulation and optical code division multiple access (OCDMA) can also be employed to share the capacity on a wavelength.

The traffic merging from different source-destination pairs is called traffic grooming. Nodes that can groom traffic are capable of multiplexing or demultiplexing lower rate traffic onto a wavelength and switch it from one lightpath to another. The traffic grooming can be either static or dynamic. In static traffic grooming the source-destination pairs for each request are predetermined. In dynamic traffic grooming, connection requests from different source-destination pairs are combined depending on the existing lightpaths at the time of the request.

The traffic grooming algorithm proposed in this work is based on the Direct-link algorithm [12] that aims at optimizing the wavelength utilization. The proposed algorithm searches an established lightpath with sufficient bandwidth. If no active lightpath offer sufficient bandwidth, then a new channel is established. This algorithm is presented as a modification of the First-Fit heuristic for wavelength assignment [2] and it is described using the following notation:

- w: wavelength index;
- $SelectedLambda$: control variable;
- L: number of links in the selected path;
- P_l: vector containing the links of the selected path;
- $\lambda(ij)$: element of the occupation matrix, indexed by the number of links i and by the wavelength j. If $\lambda(ij) = 1$, the wavelength j in the link i is busy; else, if $\lambda(ij) = 0$, in any of the links composing the path, the wavelength j is free;
- λ_{MAX}: maximum number of wavelengths per fiber;
- B_{ij}: available bandwidth in the wavelength j of the link i;

Algorithm 1 First-Fit with Traffic Grooming (FF-Ag)

Require: occupation matrix; route; transmission rate of requested connection (B_{ij})
Ensure: wavelength selected

```
w ← 1;
SelectedLambda ← FALSE;
for i ranging from 1 to L do
   if B_ij ⩽ λ(P_l, w) then
      SelectedLambda ← TRUE;
   else if w ⩽ λ_MAX then
      w ← w + 1;
   else
      return Blocked;
   end if
end for
```

V. ANALYSIS OF RESULTS

A. Simulation environment

A simulator was designed and developed to implement routing and wavelength assignment in a dynamic all-optical networks, using Python language. In this simulator, when a new request arrives, the router uses the routing table to determine the entire path from source to destination. It then attempts to assign a wavelength along this path by propagating a wavelength request to all the routers along the path. If wavelength conversion is available in the network, then a lightpath can be established using different wavelengths on different links.

If this request fails, a different wavelength is chosen, the choice can be based on the feedback from the closest node on the shortest path. This process may be repeated until there is only one wavelength available. If this fails, then the request is blocked, i.e. the lightpath cannot be set up.

For the experiments, one considers four topologies: a simple mesh-network with five nodes shown in Figure 2 a, with a small number of links; the Mesh-Torus network topology with nine nodes, shown in Figure 2 b and the National Science Foundation Network (NSFNet) topology, shown in Figure 2 c.

For the simulation each link has two unidirectional fibers, with 2 to 50 wavelengths per fiber, creating a bidirectional link. Therefore, the cost attributed to each unidirectional link may be different. The simulation stops when the maximum number of requests is reached. The number of requests is 50.000 for each number of wavelengths considered. The load was set to

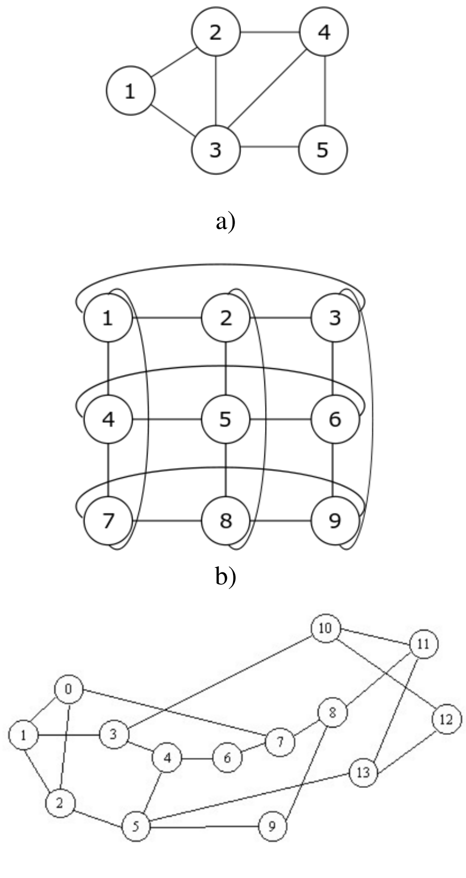

Fig. 2. Topologies used in the simulation: a) simple mesh network with five nodes, b) mesh-torus network and c) NSFNet.

500 erlangs. Each connection has a duration, or holding time, which is exponentially distributed and the arrival time has a Poisson distribution. Each wavelength support 10 Gbits/s and a granularity of 1 Gbits/s or multiple. A source-destination pair for each request is randomly determined to consider a uniformly distributed traffic in the network.

The performance of the routing algorithms is compared in terms of blocking probability, expressed as the fraction of the rejected connection requests due to wavelength unavailability divided by the total number of connection requests at the simulation run.

B. Results

The graphics of blocking probability versus number of wavelengths are shown in Figure 3, for the simple mesh network with five nodes, in Figure 4 for the mesh-torus network and Figure 5 for the NSFNet. The range of wavelengths shown in the figures represents the most significant results obtained from the simulation.

The results show that among all the algorithms considered, the fixed-alternate routing presents the best performance, with or without traffic grooming capacity. They also show that the use of traffic grooming substantially reduces the blocking in the network. This reduction can reach values around 15%, as shown in Figure 3 or 25%, as shown in Figures 4 and 5.

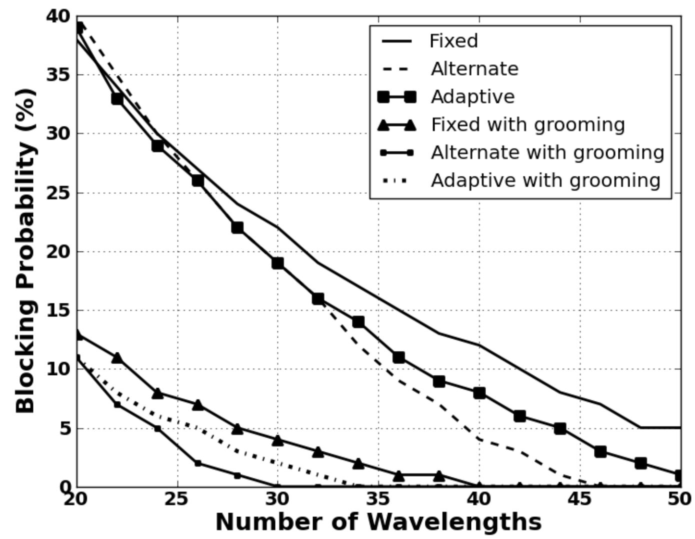

Fig. 3. Blocking probability versus number of wavelengths for the simple mesh network with five nodes.

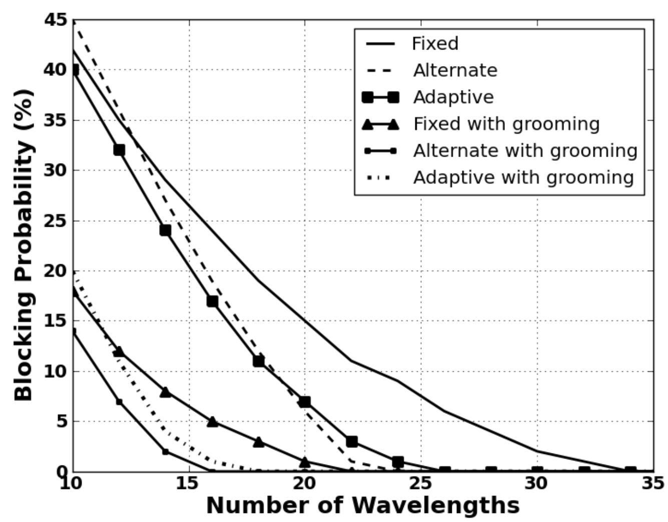

Fig. 4. Blocking probability versus number of wavelengths for the mesh-torus network.

Another important point to consider is the number of wavelengths needed for a blocking probability zero. The graphs show that the use of alternate routing with traffic aggregation leads to a need for fewer wavelengths to obtain zero blocking probability. Such information suggests a decrease of network resources to maintain a given amount of traffic.

Interestingly, the results also vary according to network topology. This can be seen from the graphics shown in Figure 6, which represent the best results for each studied

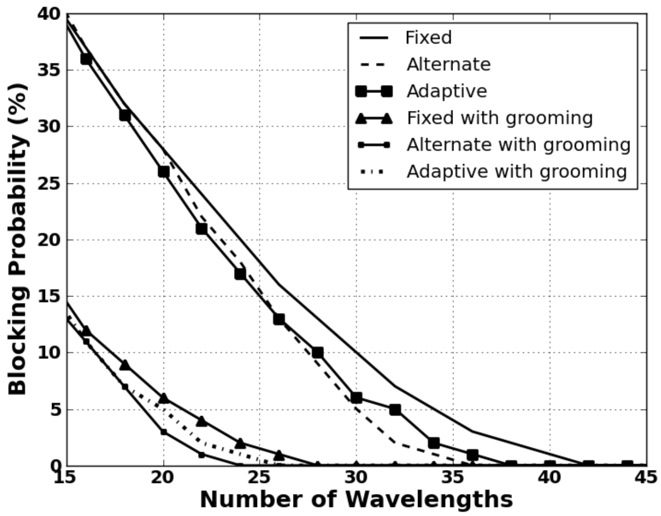

Fig. 5. Blocking probability versus number of wavelengths for the NSF network.

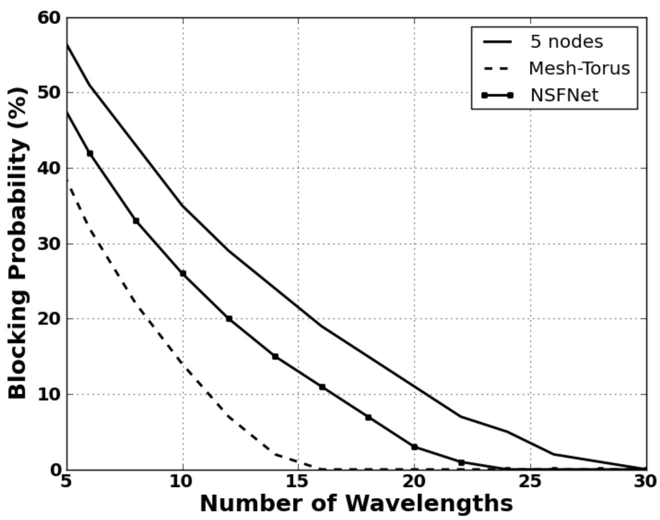

Fig. 6. Comparison of the best results in the three topologies.

topology. The figure shows results for topologies with high connection densities, i.e. larger number of connections and nodes, leading to a decrease in the blocking probability. The smallest blocking probability occurs for the mesh-torus, independent of the number of wavelengths per fiber.

VI. Conclusion

In this paper, the performance of three routing approaches in dynamic optical networks with traffic aggregation was compared regarding the blocking probability, based on the number of wavelengths per fiber.

The results show that, considering this performance metric, the fixed-alternate routing is more efficient than the fixed routing or adaptive routing. This approach leads to a decrease in blocking probability, even for a decreasing number of wavelengths.

The results vary, depending on the topology analyzed. Topologies with high densities cause low blocking probability for the same algorithm. The density is related to the number of links presented on the network, and also to the degree of connectivity of each node.

The results serve as a starting point for further analysis, which can make use of other performance metrics. For example, the average use of links or even the flow of the network. The use of other metrics can improve the performance analysis of the algorithms.

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